PHYSICS TOPICS

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Cambridge O Level Physics

Your notes

1.1 Physical Quantities & Measurement Techniques

Contents

- Measurement
- Scalars & Vectors
- Calculating with Vectors

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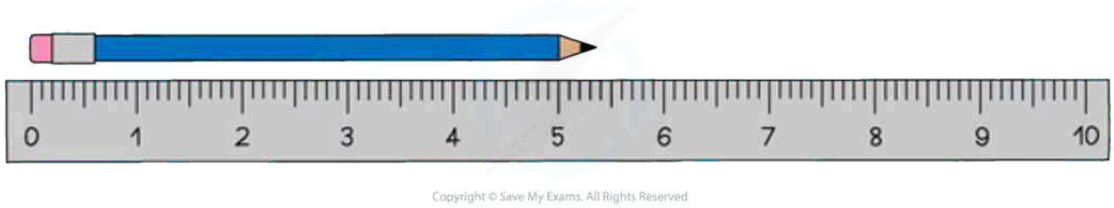
Measurement

Your notes

Measuring Length & Volume

- Rulers can be used to measure small distances of a few centimetres (cm).
 - They are able to measure to the nearest millimetre (mm)

Measuring with a ruler



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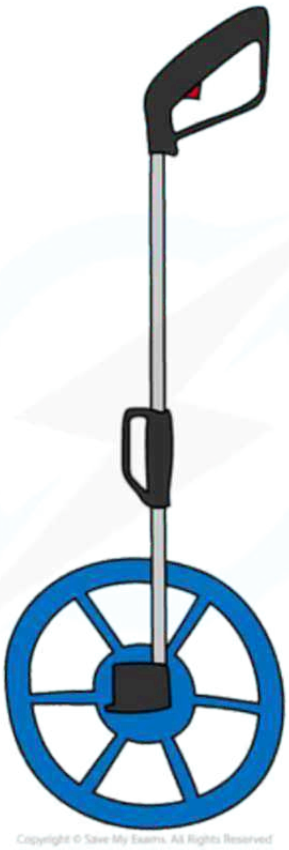
Use this image

A ruler can measure small distances to the nearest mm

- When measuring larger distances (of a few metres) a **tape measure** is more appropriate or, when measuring even larger distances, a **trundle wheel**

A trundle wheel

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Use this image

Trundle wheels can be used to measure large distances

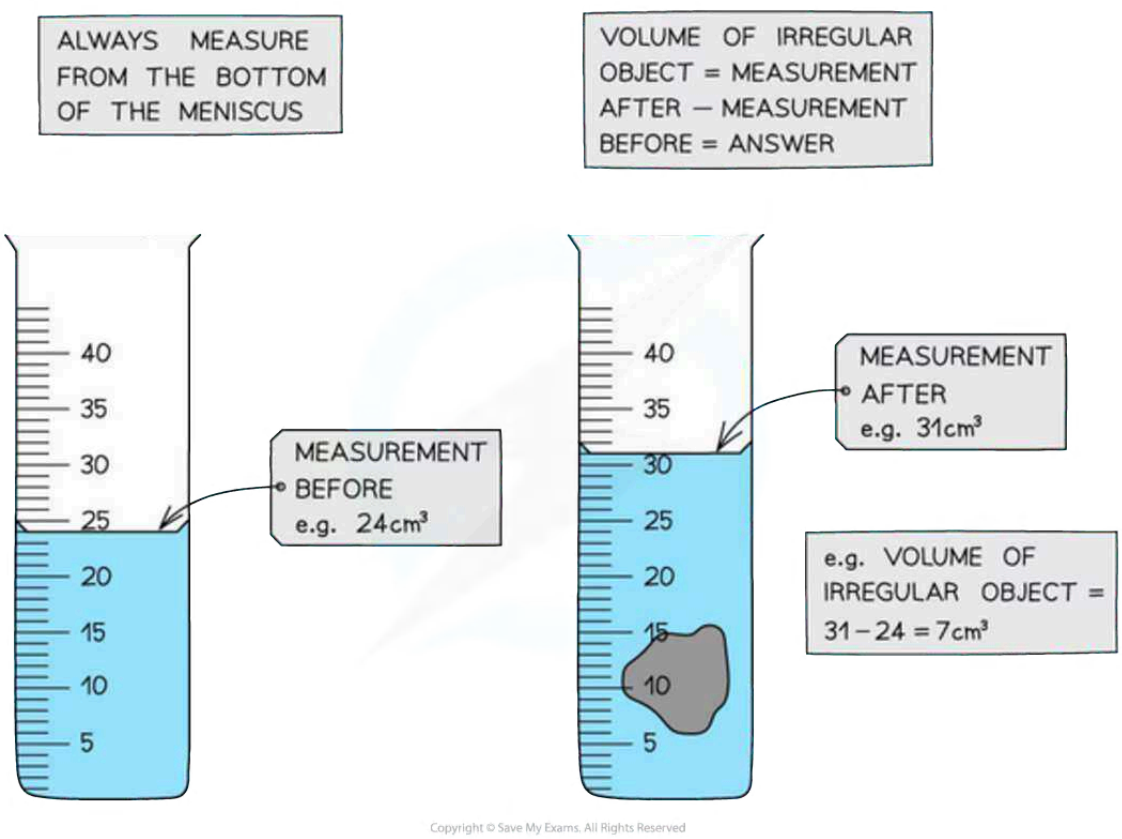
- **Measuring cylinders** can be used to measure the volume of liquids
 - By measuring the **change in volume**, a measuring cylinder can also be used to find the volume of an irregular shape

Measuring cylinders to measure volumes

Your notes

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Your notes



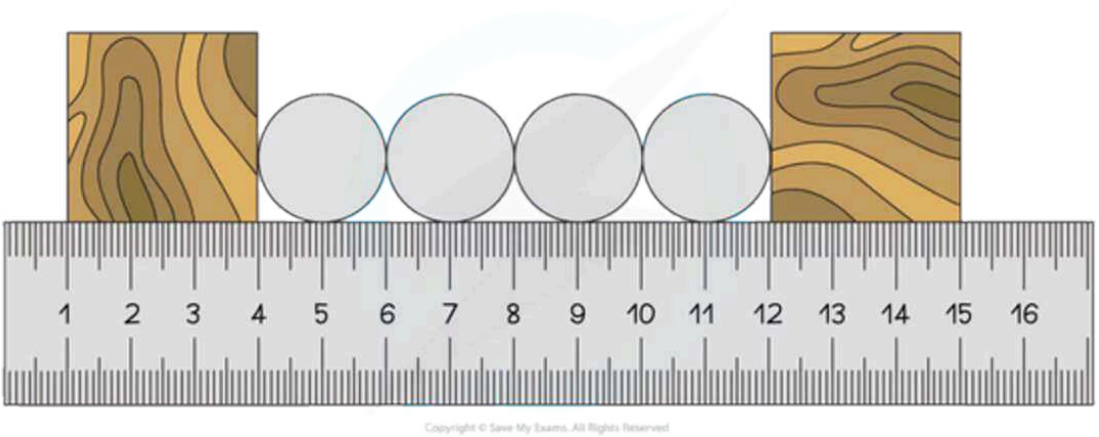
Use this image

Measuring cylinders can be used to determine the volume of a liquid or an irregular shaped solid

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Worked example

The diagram shows four identical ball-bearings placed between two blocks on a steel ruler.



Use this image

Calculate the diameter of one ball-bearing.

Answer:

Step 1: Measure the length of all four ball-bearings

- The blocks mark the edges of the first and last ball bearings
- The blocks make it easier to measure the length of all four ball-bearings

Total length = 12 cm – 4 cm = **8 cm**

Step 2: Divide the total length by the number of ball-bearings

Diameter = total length ÷ number of ball-bearings

Diameter = 8 ÷ 4

Diameter = **2 cm**

Your notes

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Measuring Time

- Stop-clocks and stopwatches can be used to measure time intervals
- An important factor when measuring time intervals is human reaction time. This can have a significant impact upon measurements when the measurements involved are very short (less than a second)



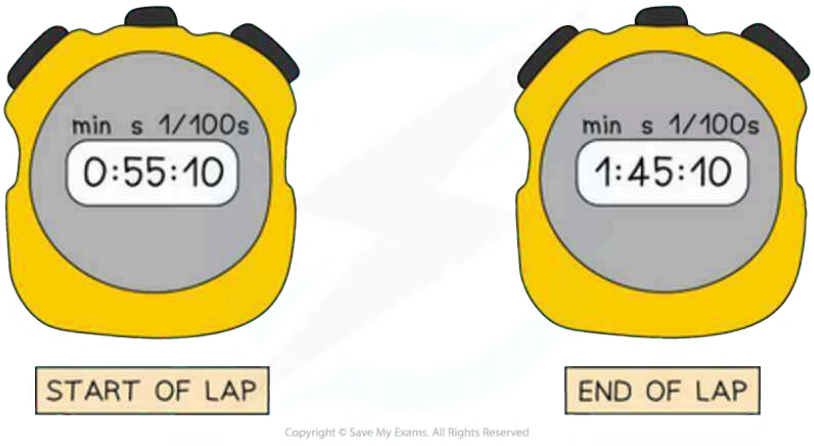
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Worked example

A stopwatch is used to measure the time taken for a runner to complete a lap of a 400 m track.

The images below give the readings on the stopwatch at the start and the end of the lap.



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Use this image

Calculate how long it took the runner to complete the lap. Give your answer in seconds.

Answer:

Step 1: Identify the start time for the lap

- The stopwatch was already at 0:55:10 when the runner started the lap
- Start time = **55.10 seconds (s)**

Step 2: Identify the finish time for the lap

- The stopwatch reads 1:45:10 at the end of the lap
- Finish time = **1 minute and 45.10 s**

Step 3: Convert the finish time into seconds

1 minute = 60 seconds

Finish time = 60 s + 45.10 s

Finish time = **105.10 s**

Your notes

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Step 4: Calculate the time taken to complete the lap

The time taken to complete the lap = finish time – start time

Time taken to complete lap = 105.10 s – 55.10 s

Time taken to complete lap = **50 s**

Exam Tip

You will sometimes find that information is given in the question that is not actually needed in the calculation.

In this worked example, you were told that the track the runner is running on is 400 m. This had nothing to do with the calculation the question asked you to perform.

This is a common method for making a question seem more difficult. Don't let it catch you out!



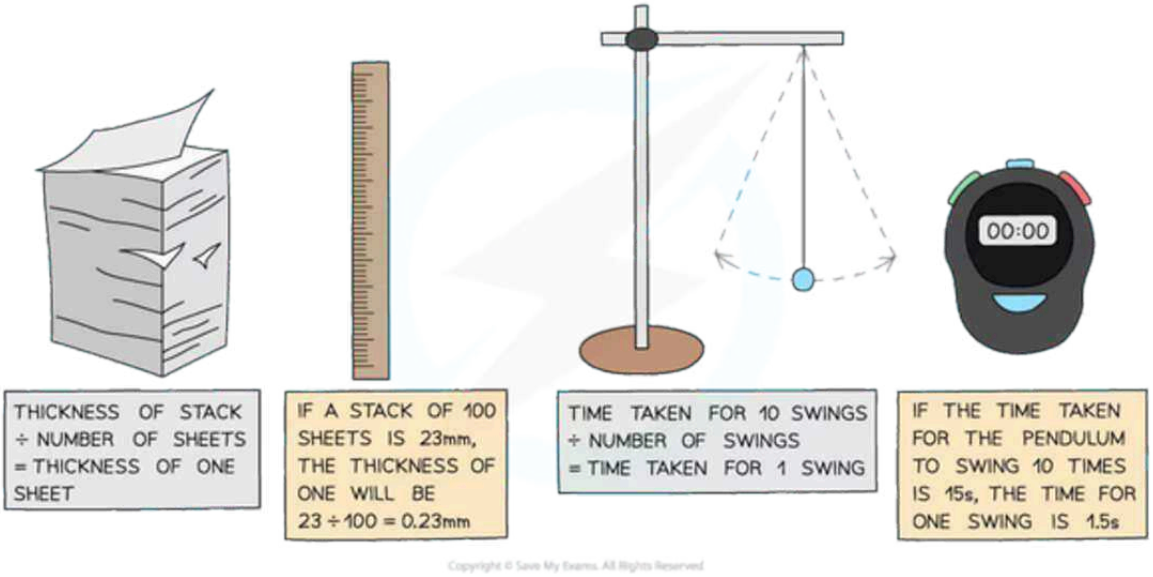
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Multiple Readings

Your notes

Multiple readings scenarios



Examples of measurements where multiple readings are needed

Use this image

- Suppose you have to measure the thickness of a sheet of paper
 - The thing that you are trying to measure is so small that it would be very difficult to get an accurate answer
- If, however, you measure the thickness of 100 sheets of paper you can do so much more accurately
 - Dividing your answer by 100 will then give an accurate figure for the thickness of one sheet
- This process of taking a reading of a large number of values and then dividing by the number, is a good way of getting accurate values for small figures, including (for example) the time period of a pendulum
 - Measure the time taken for 10 swings and then **divide that time by 10** to find the **average**

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Scalars & Vectors


Your notes

Scalar & Vector Quantities

- All quantities can be one of two types:
 - A **scalar**
 - A **vector**

Scalars

- Scalars are quantities that have only a **magnitude**
 - For example, **mass** is a scalar since it is a quantity that has magnitude without a direction
 - **Distance** is also a scalar since it only contains a magnitude, not a direction

Vectors

- Vectors have both **magnitude** and **direction**
- **Velocity**, for instance, is a vector since it is described with both a magnitude and a direction
 - When describing the velocity of a car it is necessary to mention **both** its **speed** and the **direction** in which it is travelling
 - For example, the velocity might be 60 km per hour (magnitude) due west (direction)
- **Distance** is a value describing only how long an object is or how far it is between two points - this means it is a **scalar** quantity
- **Displacement** on the other hand also describes the **direction** in which the distance is measured - this means it is a **vector** quantity
 - For example, a displacement might be 100 km north

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Examples of Scalars & Vectors


Your notes

- The table below lists some common examples of scalar and vector quantities:

Scalars and Vectors Table

Scalars	Vectors
Distance	Displacement
Speed	Velocity
Mass	Acceleration
Time	Force
Energy	Momentum
Volume	Weight (a type of force)
Density	Electric field strength
Pressure	Gravitational field strength
Electric charge	
Temperature	

- Some vectors and scalars are similar to each other
 - For example, the scalar quantity **distance** corresponds to the vector quantity **displacement**
- Corresponding vectors and their scalar counterparts are aligned in the table where applicable

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Worked example

Blu is in charge of training junior astronauts. For one of his sessions, he would like to explain the difference between mass and weight.

Suggest how Blu should explain the difference between mass and weight, using definitions of scalars and vectors in your answer.

Answer:

Step 1: Recall the definitions of a scalar and vector quantity

- Scalars are quantities that have only a **magnitude**
- Vectors are quantities that have both **magnitude and direction**

Step 2: Identify which quantity has magnitude only

- **Mass** is a quantity with **magnitude** only
- So mass is a **scalar** quantity
 - Blu might explain to his junior astronauts that their mass will not change if they travel to outer space

Step 3: Identify which quantity has magnitude and direction

- **Weight** is a quantity with **magnitude and direction** (it is a force)
- So weight is a **vector** quantity
 - Blu might explain to his junior astronauts that their weight - the force on them due to gravity - will vary depending on their distance from the centre of the Earth

Exam Tip

Make sure you are comfortable with the differences between **similar** scalars and vectors, the most commonly confused pairings tend to be:

- Distance and displacement
- Speed and velocity
- Weight and mass

Your notes

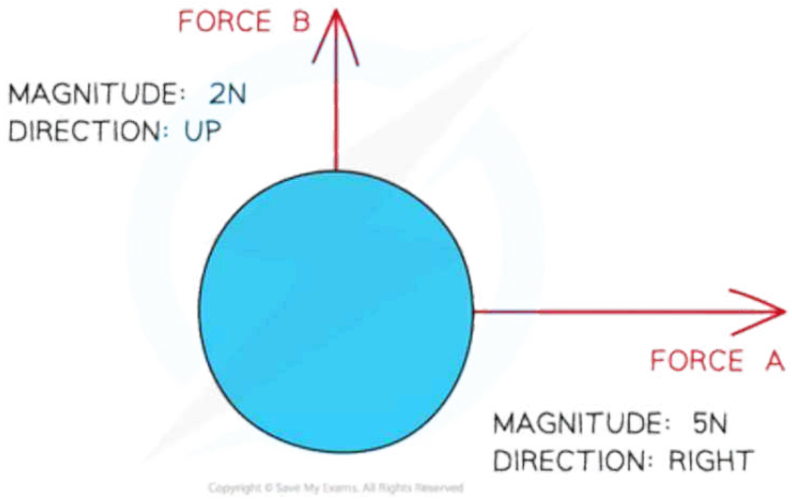
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Calculating with Vectors

Your notes

Calculations with Vectors

- **Vectors** are represented by an arrow
 - The **arrowhead** indicates the **direction** of the vector
 - The **length** of the arrow represents the **magnitude**



The two force vectors acting on the object have both a direction and a magnitude

- **Component** vectors are sometimes drawn with a dotted line and a **subscript** indicating horizontal or vertical
 - For example, F_V is the vertical component of the force F

Calculating Vectors Graphically

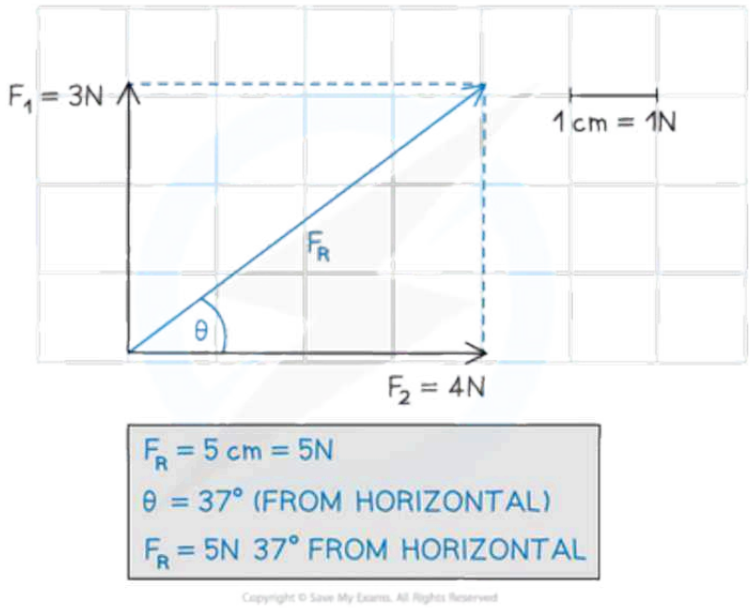
- Vectors at right angles to one another can be **combined** into one **resultant vector**
 - The resultant vector will have the same effect as the two original ones
- To calculate vectors graphically means carefully producing a scale drawing with all lengths and angles correct
 - This should be done using a sharp **pencil**, **ruler** and **protractor**
- Follow these steps to carry out calculations with vectors on graphs
 1. Choose a **scale** which fits the page
 - For example, use 1 cm = 10 m or 1 cm = 1 N, so that the diagram is around 10 cm high
 2. Draw the vectors at **right angles** to one another
 3. Complete the rectangle

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4. Draw the **resultant vector** diagonally from the origin
5. Carefully **measure the length** of the resultant vector
6. Use the scale factor to calculate the **magnitude**
7. Use the protractor to measure the **angle**

Your notes

Vector drawn to scale



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Vectors can be measured or calculated graphically if you are confident in using scales

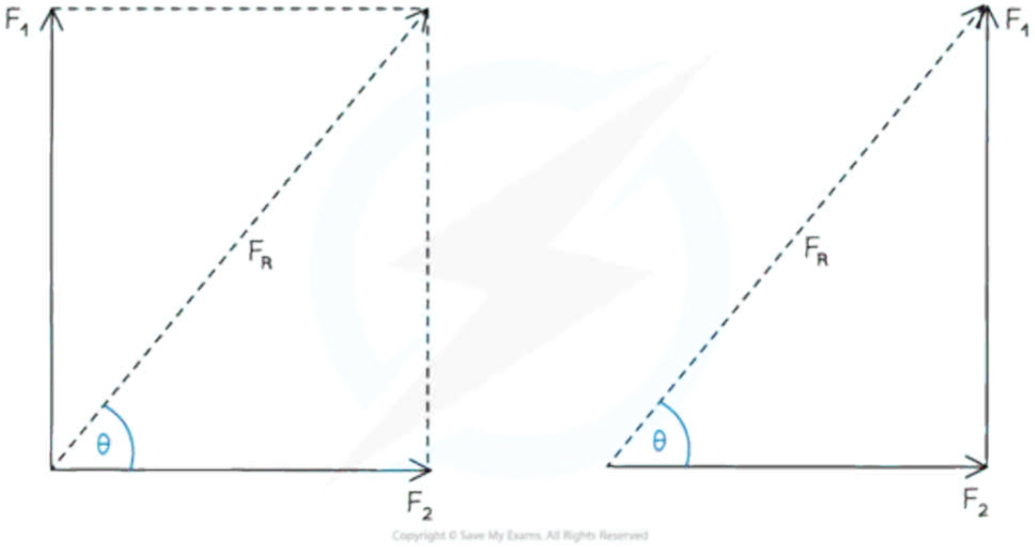
Combining Vectors by Calculation

- In this method, a diagram is still essential but it does **not** need to be exactly to scale
- The diagram can take the form of a sketch, as long as the resultant, component and sides are clearly labelled

Resolving vectors

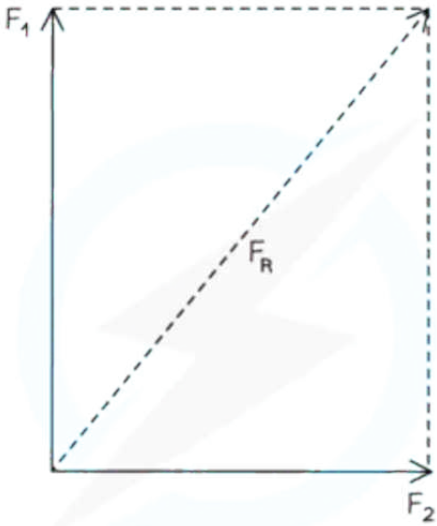
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Resolving two force vectors F_1 and F_2 into a resultant force vector F_R

Resultant vector



RESULTANT FORCE = EFFECT OF FORCE 1 + EFFECT OF FORCE 2

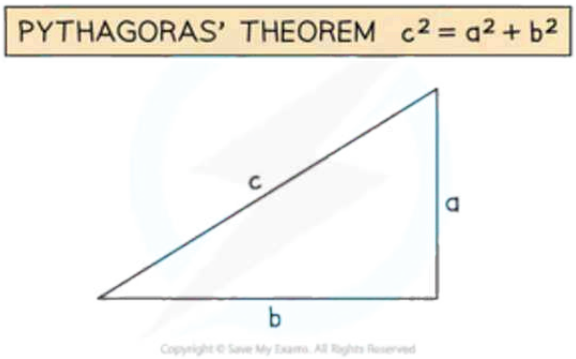
$$F_R^2 = F_1^2 + F_2^2$$

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- Use **Pythagoras' Theorem** to find the resultant vector

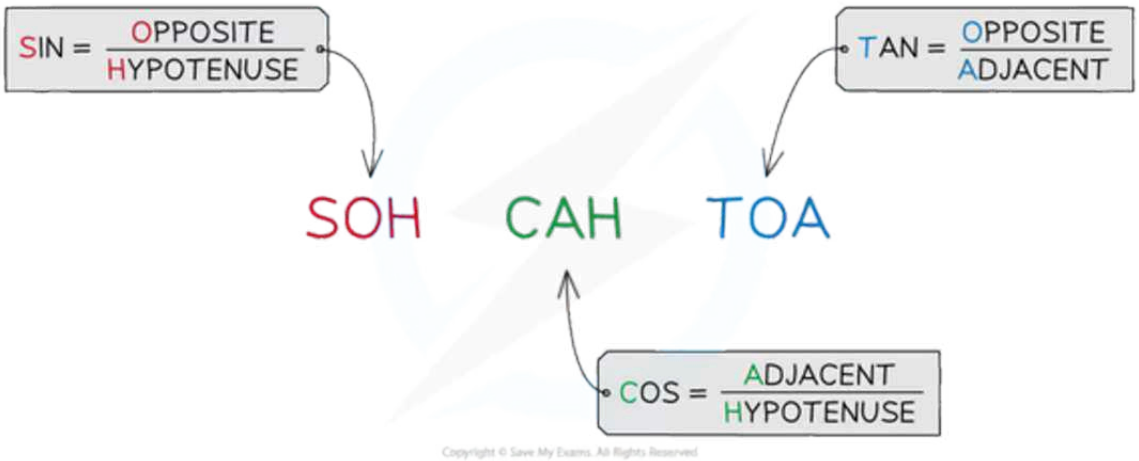
Your notes

Pythagoras' Theorem

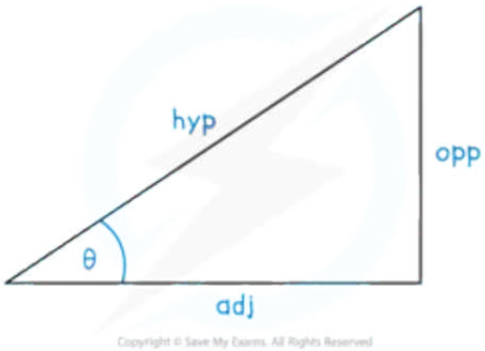


Pythagoras's Theorem makes calculating vectors at right angles much simpler

- Use **trigonometry** to find the angle
- The mnemonic '**soh-cah-toa**' is used to remember how to apply sines and cosines to resolve the sides of a triangle



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Trigonometry and Pythagoras' Therom are essential in vector calculations

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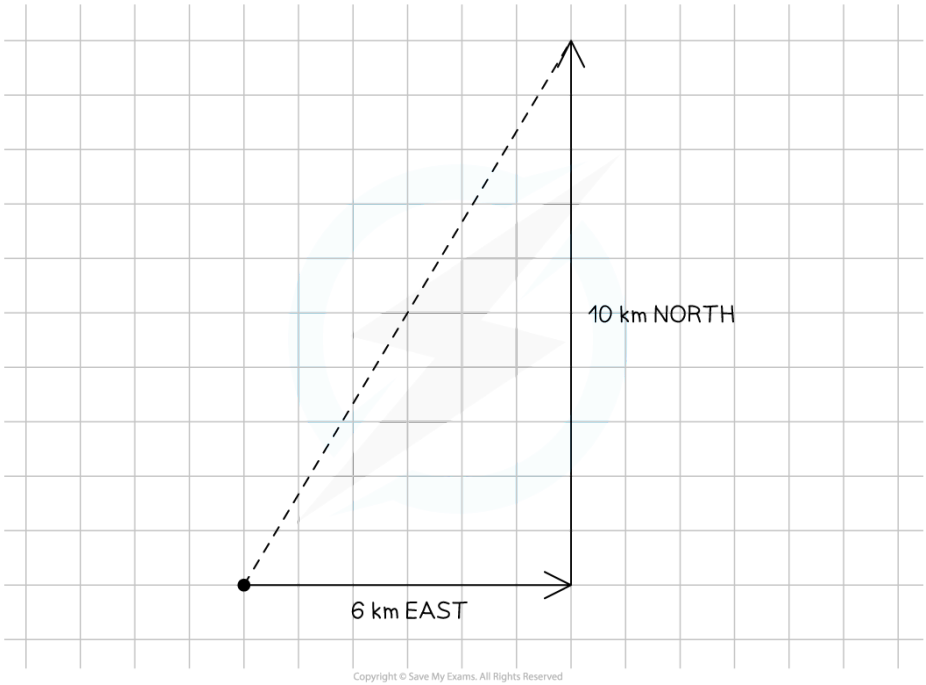
Worked example

A hiker walks a distance of 6 km due east and 10 km due north.

Calculate the magnitude of their displacement and its direction from the horizontal.

Answer:

Step 1: Draw a vector diagram



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Step 2: Calculate the magnitude of the resultant vector using Pythagoras' Theorem

$$\text{Resultant vector} = \sqrt{6^2 + 10^2}$$

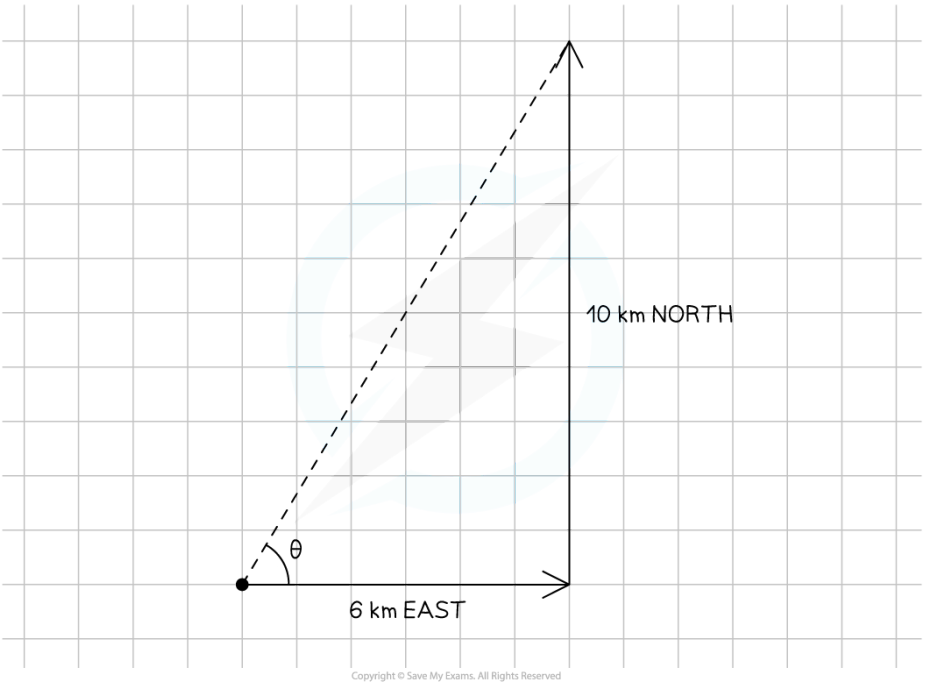
$$\text{Resultant vector} = \sqrt{136}$$

Resultant vector = **11.66**

Step 3: Calculate the direction of the resultant vector using trigonometry

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Your notes



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$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{10}{6}$$

$$\theta = \tan^{-1}\left(\frac{10}{6}\right) = 59°$$

Step 4: State the final answer complete with direction

Resultant vector = **12 km 59° east and upwards from the horizontal**

Exam Tip

If the question specifically asks you to use the calculation or graphical method, you must solve the problem as asked. However, if the choice is left up to you then any correct method will lead to the correct answer.

The graphical method sometimes feels easier than calculating, but once you are confident with trigonometry and Pythagoras you will find calculating quicker and more accurate.

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Cambridge O Level Physics

Your notes

1.2 Motion

Contents

- Speed & Velocity
- Acceleration
- Distance-Time Graphs
- Speed-Time Graphs
- Calculating Acceleration from Speed-Time Graphs
- Freefall

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Speed & Velocity

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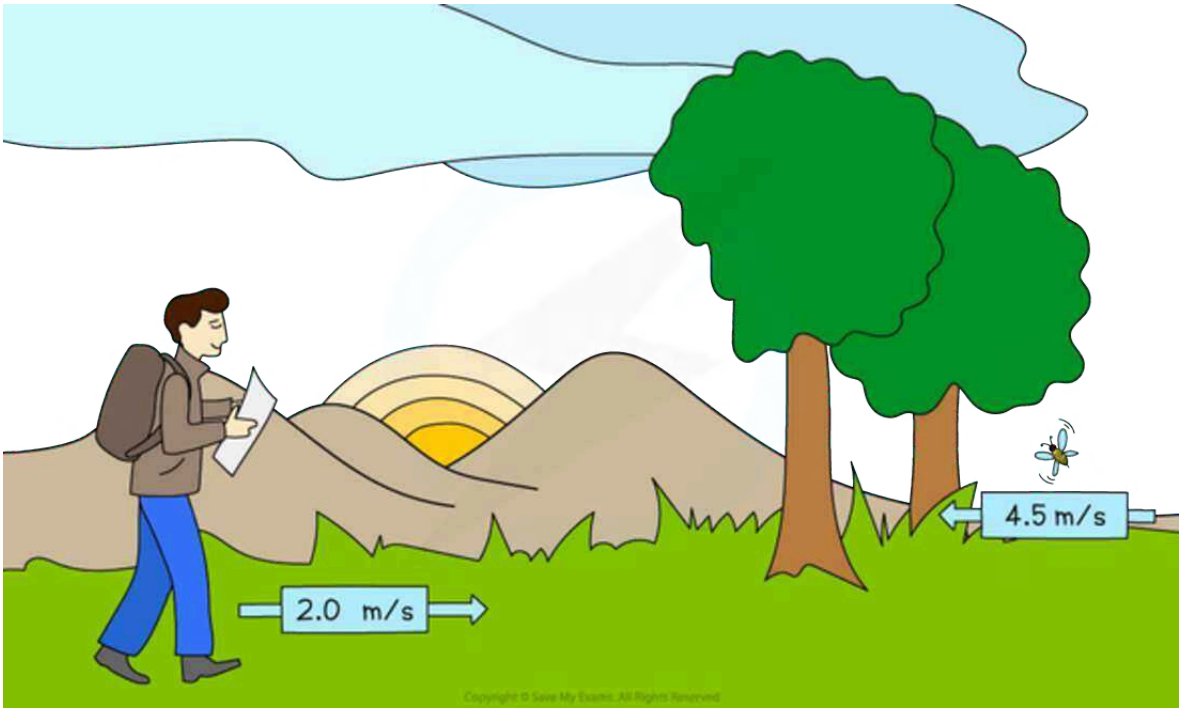
Speed

- The **speed** of an object is the distance it travels per unit time
- Speed is a **scalar** quantity
 - This is because it only contains a magnitude (without a direction)
- For objects that are moving with a constant speed, use the equation below to calculate the speed:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

- Where:
 - Speed is measured in metres per second (m/s)
 - Distance travelled is measured in metres (m)
 - Time taken is measured in seconds (s)

Different speeds



A hiker might have an average speed of 2.0 m/s, whereas a particularly excited bumble bee can have average speeds of up to 4.5 m/s

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Average Speed

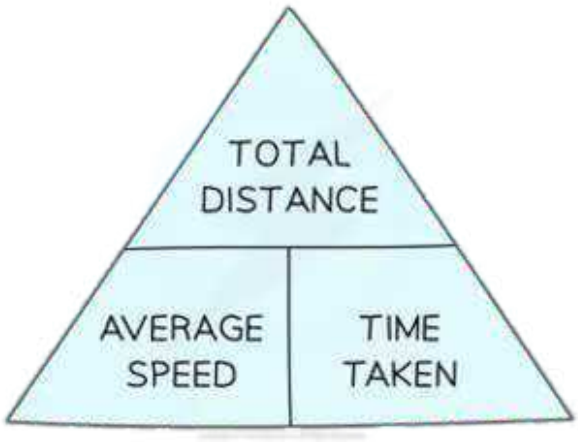
Your notes

- In some cases, the speed of a moving object is not constant
 - For example, the object might be moving faster or slower at certain moments in time (accelerating and decelerating)
- The equation for calculating the **average speed** of an object is:

$$Average\ speed = \frac{distance\ travelled}{time\ taken}$$

- The formula for **average speed** (and the formula for **speed**) can be rearranged with the help of the formula triangle below:

Average speed equation triangle



Average speed, total distance and time taken equation triangle

How to Use Formula Triangles

- Formula triangles are really useful for knowing how to rearrange physics equations
- To use them:

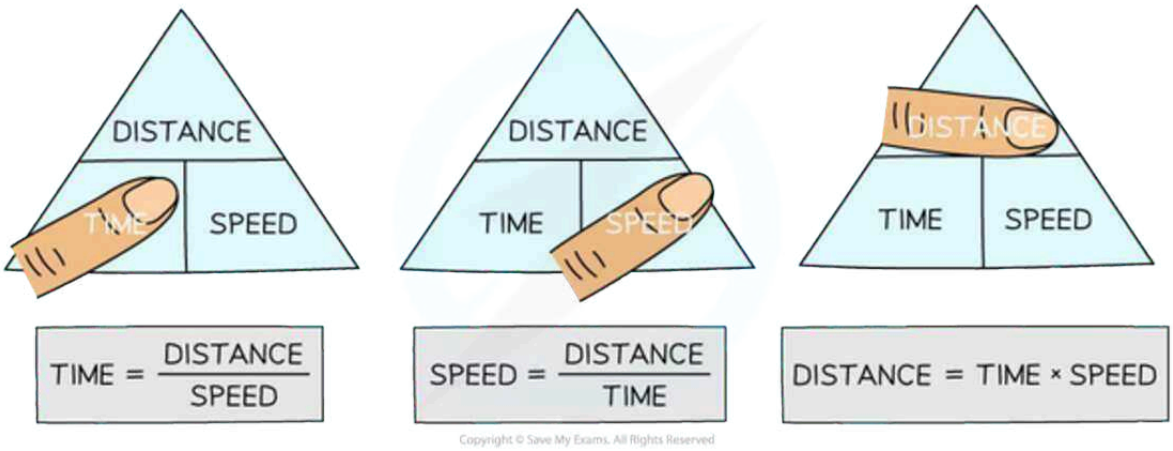
1. Cover up the quantity to be calculated, this is known as the 'subject' of the equation
2. Look at the position of the other two quantities
 - If they are on the same line, this means they are **multiplied**
 - If one quantity is above the other, this means they are **divided** - make sure to keep the order of which is on the top and bottom of the fraction!

- In the example below, to calculate speed, cover-up 'speed' and only distance and time are left
 - This means it is equal to distance (on the top) ÷ time (on the bottom)

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Your notes

Formula triangle example



How to use formula triangles

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Worked example

Planes fly at typical speeds of around 250 m/s. Calculate the total distance travelled by a plane moving at this average speed for 2 hours.

Answer:

Step 1: List the known quantities

- Average speed = 250 m/s
- Time taken = 2 hours

Step 2: Write the relevant equation

$$\square\square\square\square\square\square\square\ \square\square\square\square\square = \frac{\square\square\square\square\square\square\square\ \square\square\square\square\square\square\square\square\square}{\square\square\square\square\ \square\square\square\square\square}$$

Step 3: Rearrange for the total distance

$$\text{total distance} = \text{average speed} \times \text{time taken}$$

Step 4: Convert any units

- The time given in the question is not in standard units
- Convert 2 hours into seconds:

$$2 \text{ hours} = 2 \times 60 \times 60 = 7200 \text{ s}$$

Step 5: Substitute the values for average speed and time taken

$$\text{total distance} = 250 \times 7200 = 1\,800\,000 \text{ m}$$

Your notes

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Velocity

Your notes

- The **velocity** of a moving object is similar to its speed, except it also describes the object's **direction**
 - The speed of an object only contains a magnitude - it's a **scalar** quantity
- Velocity is therefore a **vector** quantity because it describes both magnitude and direction
 - e.g. '15 m/s south' or '250 mph on a bearing of 030°'

Speed vs. velocity



Two objects can have the same speed but a different velocity

- This means velocity can also have a **negative** value
 - E.g. a ball thrown upwards at a velocity of 3 m/s comes down at a velocity -5 m/s, if upwards is considered positive
 - However, their **speeds** are still 3 m/s and 5 m/s respectively
- The equation for velocity is very similar to the equation for speed:

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

$$v = \frac{s}{t}$$

- Where:
 - v = velocity in metres per second (m/s)
 - s = displacement, measured in metres (m)
 - t = time, measured in seconds (s)
- Velocity is a vector quantity, so it uses displacement, s, rather than distance which is scalar.

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Acceleration


Your notes

Acceleration

- **Acceleration** is defined as the **rate of change of velocity**
 - In other words, it describes how much an object's velocity **changes** every **second**
- The equation below is used to calculate the average acceleration of an object:

$$acceleration = \frac{change\ in\ velocity}{change\ in\ time}$$

$$a = \frac{\Delta v}{\Delta t}$$

- Where:
 - a = acceleration in metres per second squared (m/s^2)
 - Δv = change in velocity in metres per second (m/s)
 - Δt = time taken in seconds (s)
- The **change in velocity** is found by the **difference** between the initial and final velocity, as written below:

change in velocity = final velocity – initial velocity

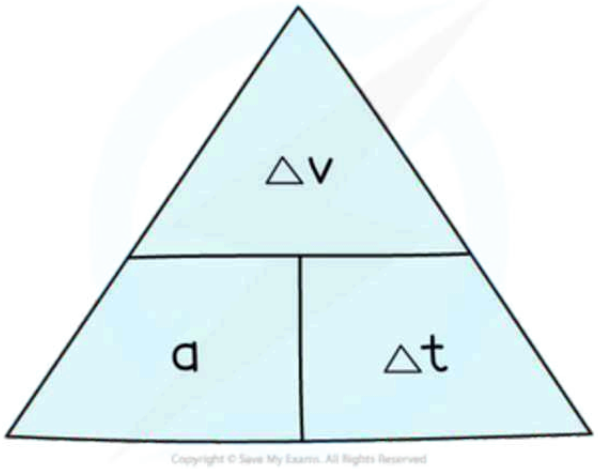
$$\Delta v = v - u$$

- Where:
 - v = final velocity in metres per second (m/s)
 - u = initial velocity in metres per second (m/s)
- The equation for acceleration can be rearranged with the help of a formula triangle as shown:

Acceleration equation triangle

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Your notes



Equation triangle for the change in velocity, acceleration, and change in time

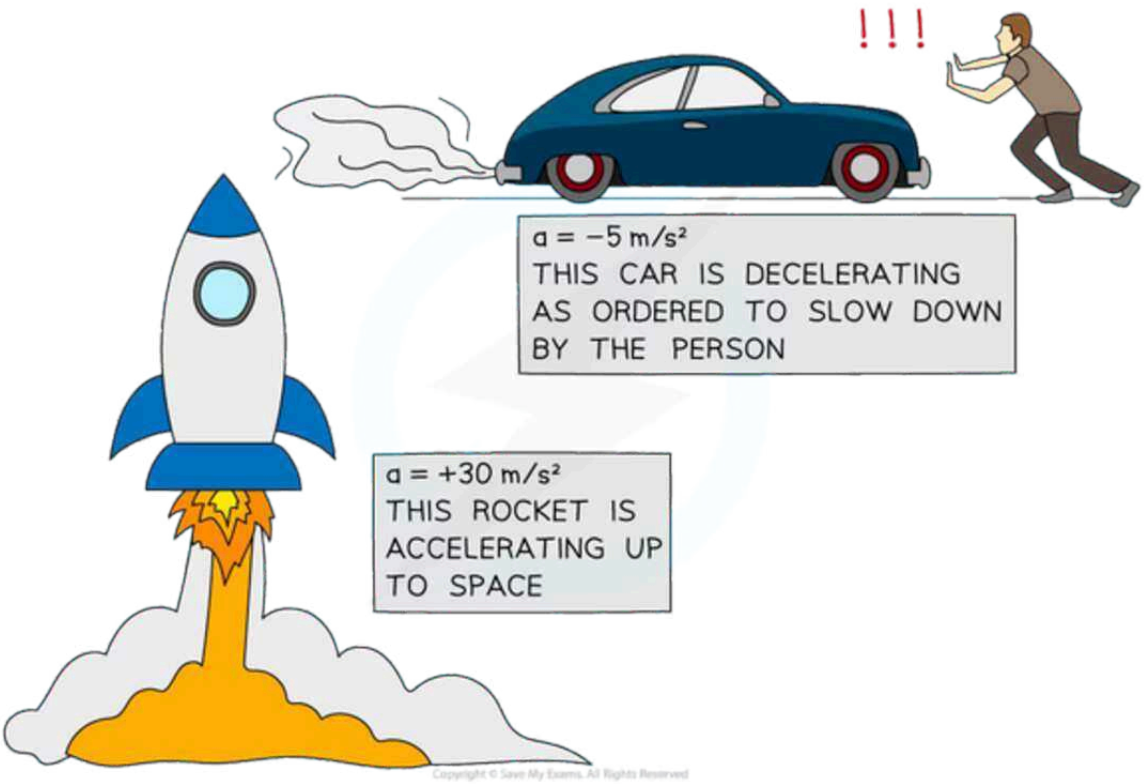
Speeding Up & Slowing Down

- An object that speeds up is **accelerating**
- An object that slows down is **decelerating**
- The **acceleration** of an object can be **positive** or **negative**, depending on whether the object is speeding up or slowing down
 - If an object is **speeding up**, its acceleration is **positive**
 - If an object is **slowing down**, its acceleration is **negative** (sometimes called **deceleration**)

Acceleration and deceleration

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Your notes



A rocket speeding up (accelerating) and a car slowing down (decelerating)

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Your notes

Worked example

A Japanese bullet train decelerates at a constant rate in a straight line. The velocity of the train decreases from 50 m/s to 42 m/s in 30 seconds.

(a) Calculate the change in velocity of the train.

(b) Calculate the deceleration of the train, and explain how your answer shows the train is slowing down.

Answer:

Part (a)

Step 1: List the known quantities

- Initial velocity = 50 m/s
- Final velocity = 42 m/s

Step 2: Write the relevant equation

change in velocity = final velocity – initial velocity

Step 3: Substitute values for final and initial velocity

change in velocity = 42 – 50 = –8 m/s

Part (b)

Step 1: List the known quantities

- Change in velocity, Δv = – 8 m/s
- Time taken, t = 30 s

Step 2: Write the relevant equation

$$a = \frac{\Delta v}{\Delta t}$$

Step 3: Substitute the values for change in velocity and time

a = –8 ÷ 30 = –0.27 m/s

Step 4: Interpret the value for deceleration

- The answer is **negative**, which indicates the train is **slowing down**

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Exam Tip

Remember the units for acceleration are **metres per second squared**, m/s^2. In other words, acceleration measures how much the velocity (in m/s) changes every second, m/s/s.

Your notes

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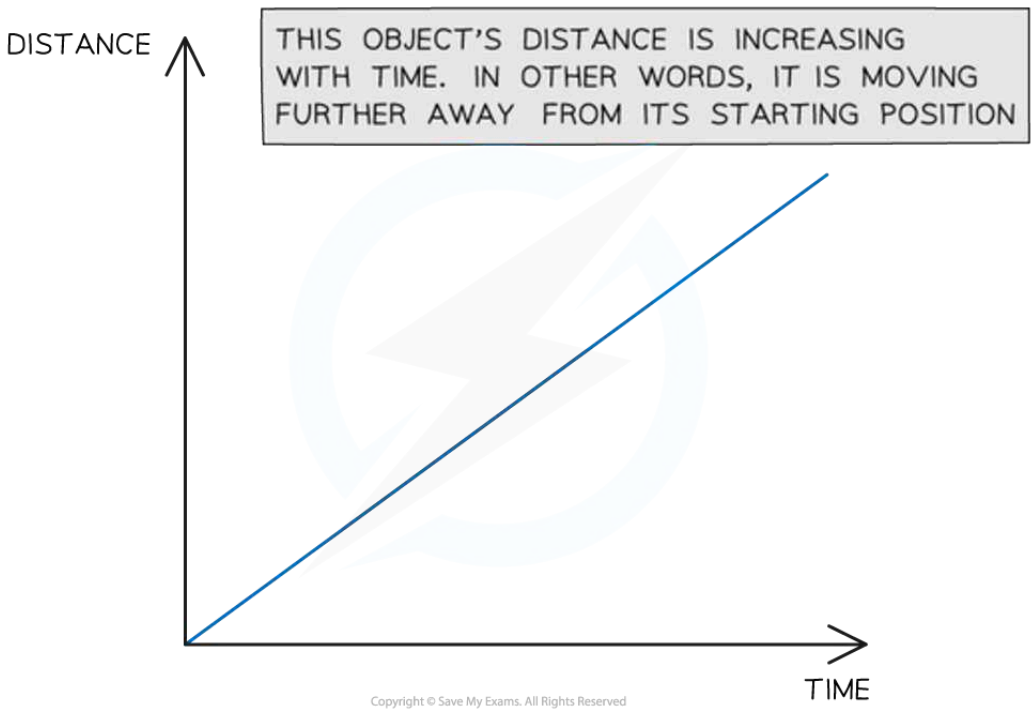
Distance-Time Graphs

Your notes

Distance-Time Graphs

- A distance-time graph shows how the **distance** of an object moving in a straight line (from a starting position) varies over time:

Distance-time graph



This graph shows a moving object moving further away from its origin

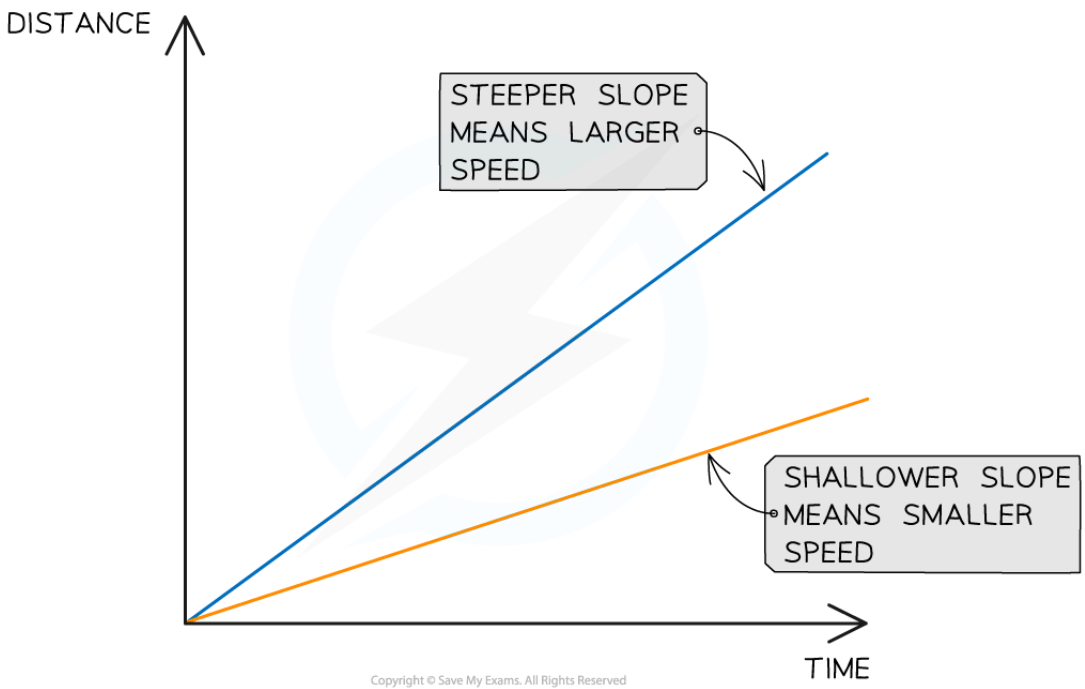
Constant Speed on a Distance-Time Graph

- Distance-time graphs also show the following information:
 - If the object is moving at a **constant speed**
 - How **large** or **small** the speed is
- A **straight line** represents **constant speed**
- The slope of the straight line represents the **magnitude** of the speed:
 - A very **steep** slope means the object is moving at a **large** speed
 - A **shallow** slope means the object is moving at a **small** speed
 - A **flat**, **horizontal line** means the object is **stationary** (not moving)

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Your notes

Faster and slower speed on a distance-time graph



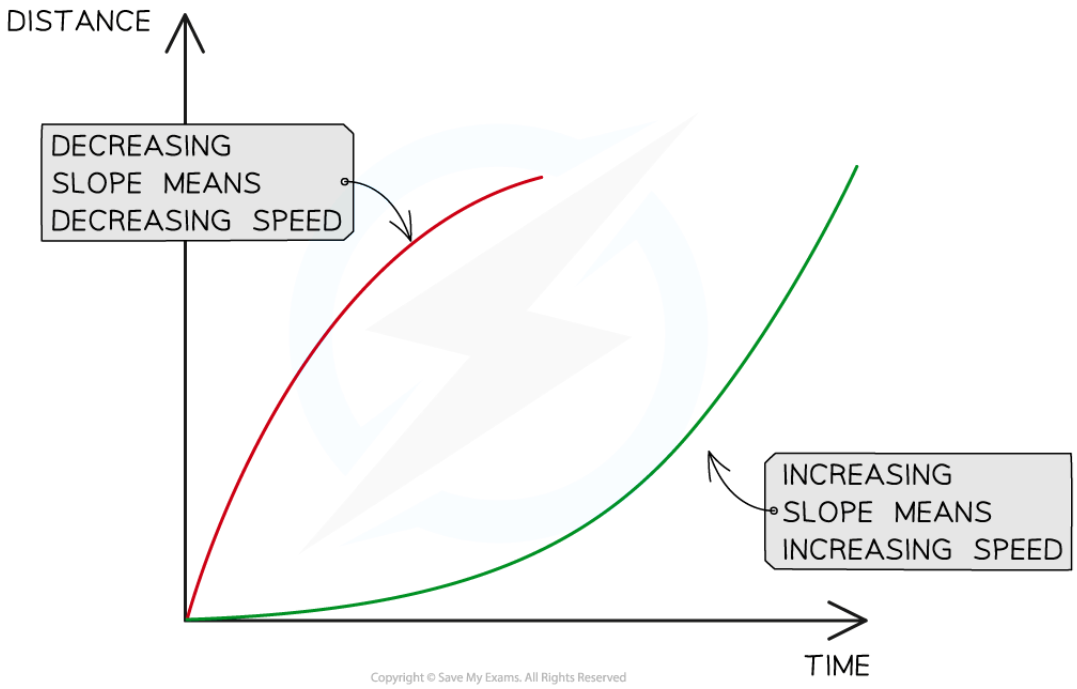
This graph shows how the slope of a line is used to interpret the speed of moving objects. Both of these objects are moving with a constant speed, because the lines are straight.

Changing Speed on a Distance-Time Graph

- Objects might be moving at a **changing speed**
 - This is represented by a **curve**
- In this case, the slope of the line will be changing
 - If the slope is **increasing**, the **speed** is **increasing** (accelerating)
 - If the slope is **decreasing**, the **speed** is **decreasing** (decelerating)
- The image below shows two different objects moving with changing speeds

Acceleration and deceleration on a distance-time graph

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Changing speeds are represented by changing slopes. The red line represents an object slowing down and the green line represents an object speeding up.

Your notes

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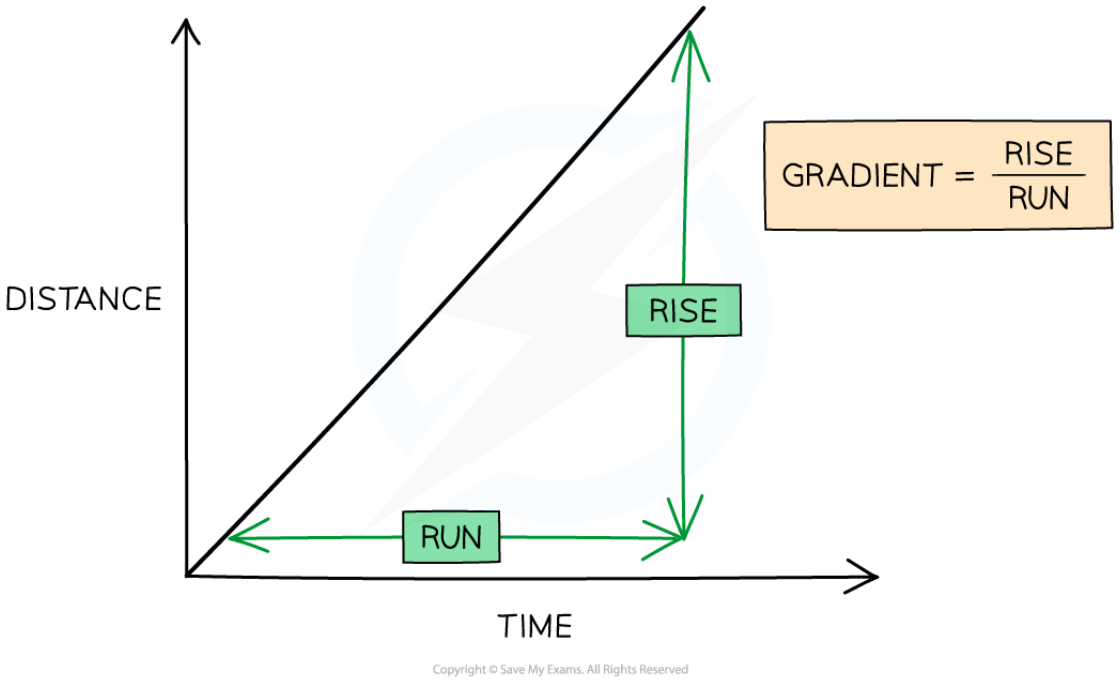
Using Distance-Time Graphs

Your notes

- The **speed** of a moving object can be calculated from the **gradient** of the line on a **distance-time** graph:

□□□□□ = □□□□□□□□□ = □□□□/□□□

Gradient of a distance-time graph



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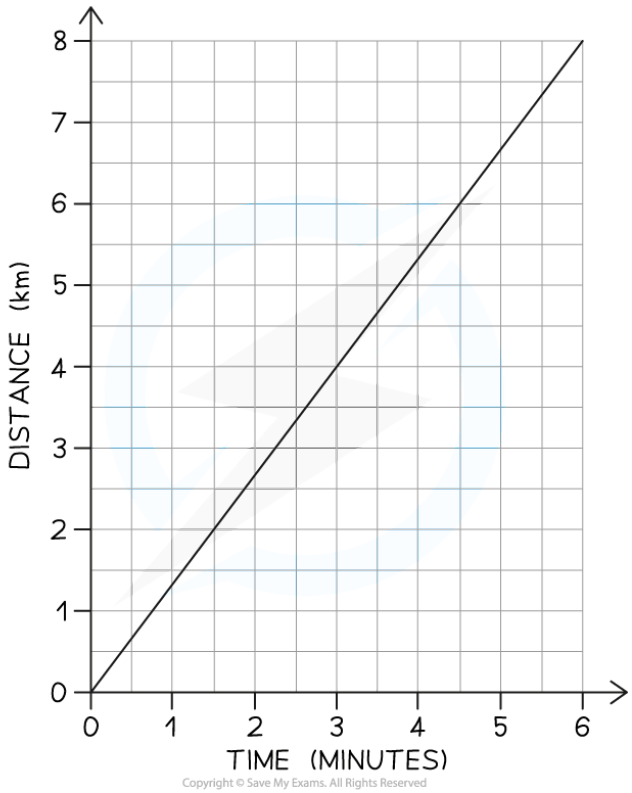
The speed of an object can be found by calculating the gradient of a distance-time graph

- The **rise** is the **change** in y (distance) values
- The **run** is the **change** in x (time) values

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Worked example

A distance-time graph is drawn below for part of a train journey. The train is travelling at a constant speed.



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Calculate the speed of the train.

Answer:

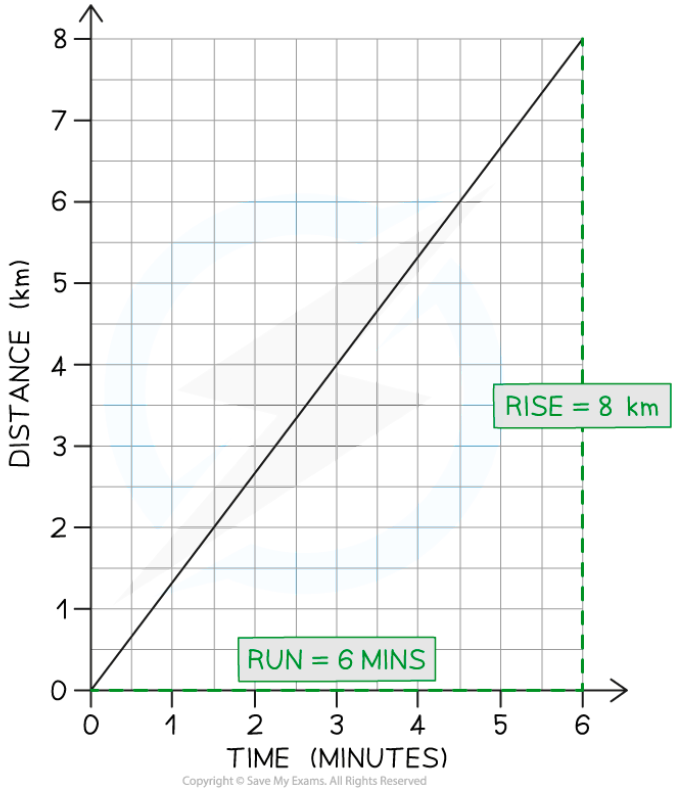
Step 1: Draw a large gradient triangle on the graph and label the magnitude of the rise and run

- The image below shows a large **gradient triangle** drawn with dashed lines
- The **rise** and **run** magnitude is labelled, using the **units** as stated on each axes

Your notes

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Your notes



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Step 2: Convert units for distance and time into standard units

- The distance travelled (rise) = 8 km = **8000 m**
- The time taken (run) = 6 mins = **360 s**

Step 3: State that speed is equal to the gradient of a distance-time graph

- The **gradient** of a **distance-time** graph is equal to the **speed** of a moving object:

Step 4: Substitute values in to calculate the speed

speed = gradient = 8000 ÷ 360 = **22.2 m/s**

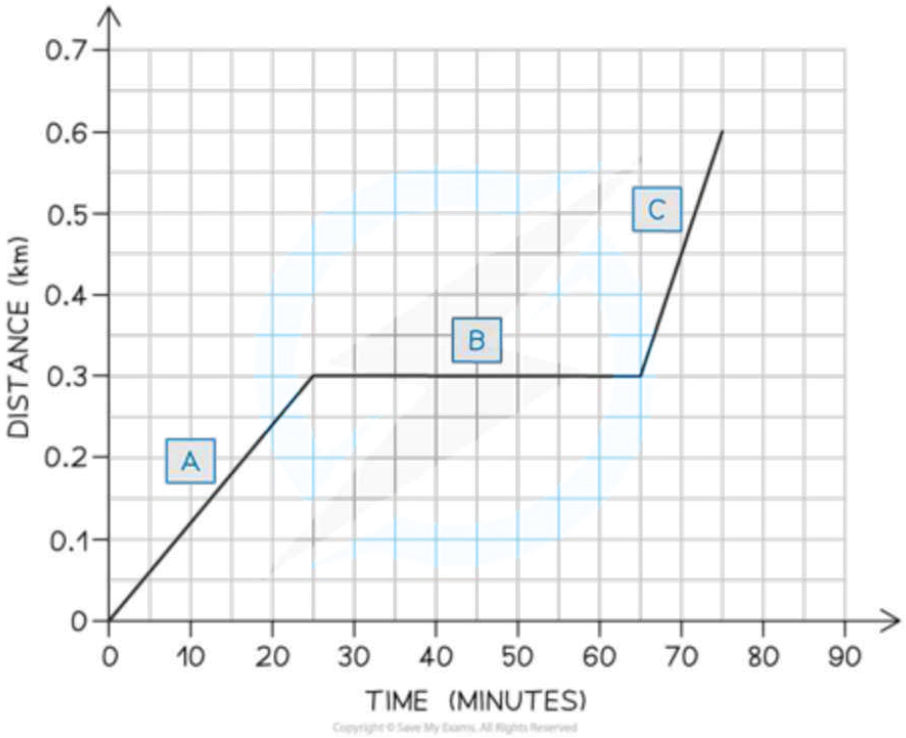
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Your notes

Worked example

Ose decides to take a stroll to the park. He finds a bench in a quiet spot and takes a seat, picking up where he left off reading his book on Black Holes. After some time reading, Ose realises he lost track of time and runs home.

A distance-time graph for his trip is drawn below.



a) How long does Ose spend reading his book?
b) There are three sections labelled on the graph, A, B and C. Which section represents Ose running home?
c) What is the total distance travelled by Ose?
d

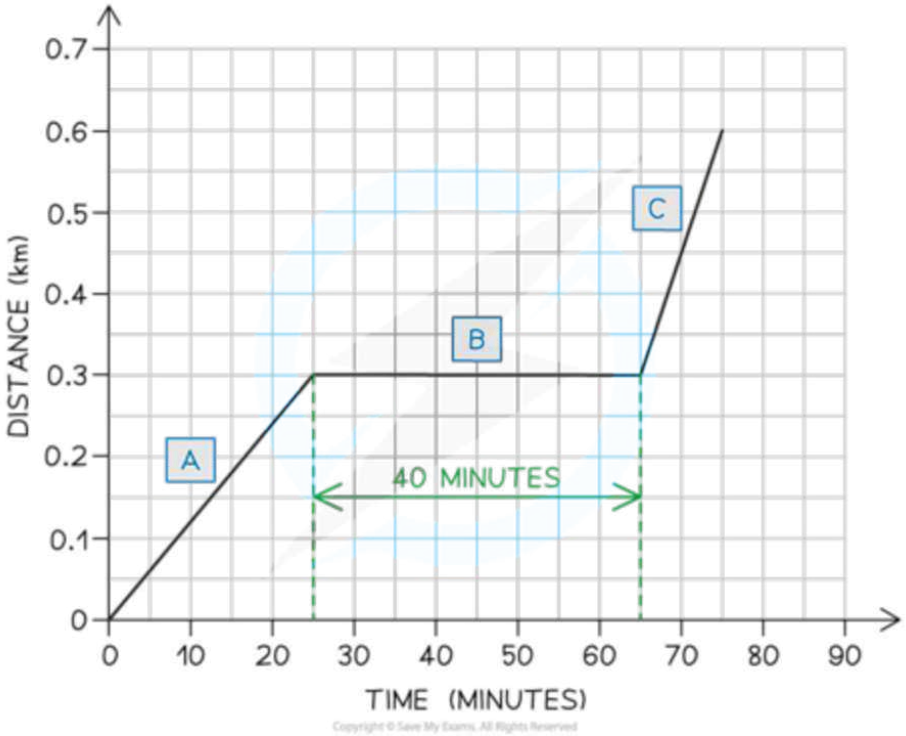
Answer:

Part (a)

- Ose spends **40 minutes** reading his book
- The **flat** section of the line (section B) represents an object which is **stationary** - so section B represents Ose sitting on the bench reading

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- This section lasts for **40 minutes** - as shown in the graph below



Your notes

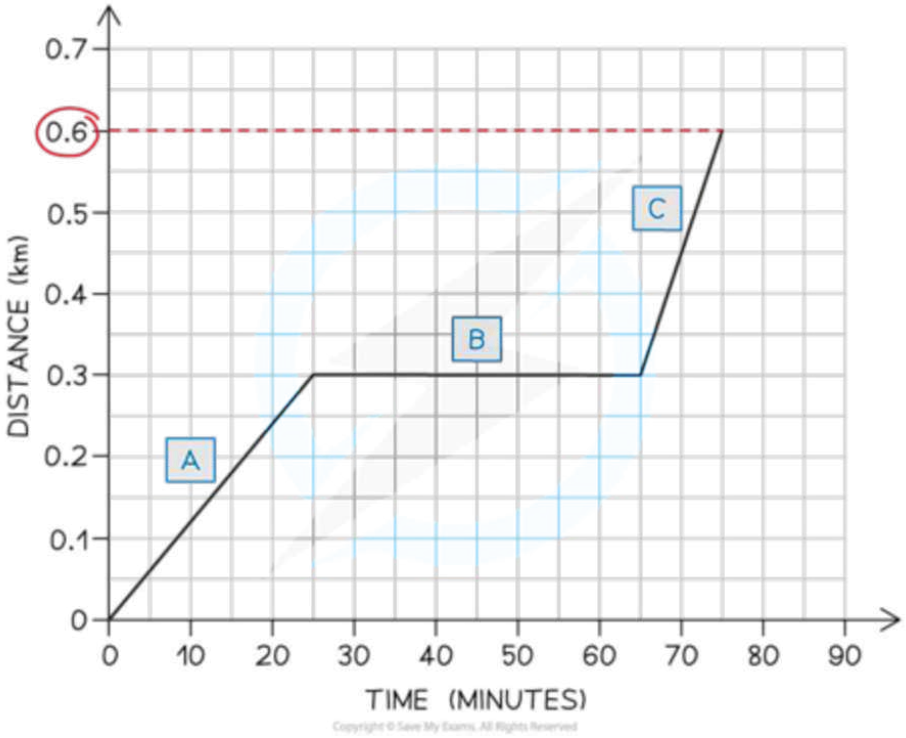
Part (b)

- **Section C** represents Ose running home
- The **slope** of the line in section C is **steeper** than the slope in section A
- This means Ose was moving with a **larger** speed (running) in section C

Part (c)

- The total distance travelled by Ose is **0.6 km**
- The total **distance** travelled by an object is given by the final point on the line - in this case, the line ends at **0.6 km** on the **distance** axis. This is shown in the image below:

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Your notes

Exam Tip

Use the **entire line**, where possible, to calculate the gradient. Examiners tend to award credit if they see a **large gradient triangle** used - so remember to draw these directly on the graph itself!

Remember to check the **units** of variables measured on each axis. These may not always be in standard units - in our example, the unit of distance was **km** and the unit of time was **minutes**. Double-check which units to use in your answer.

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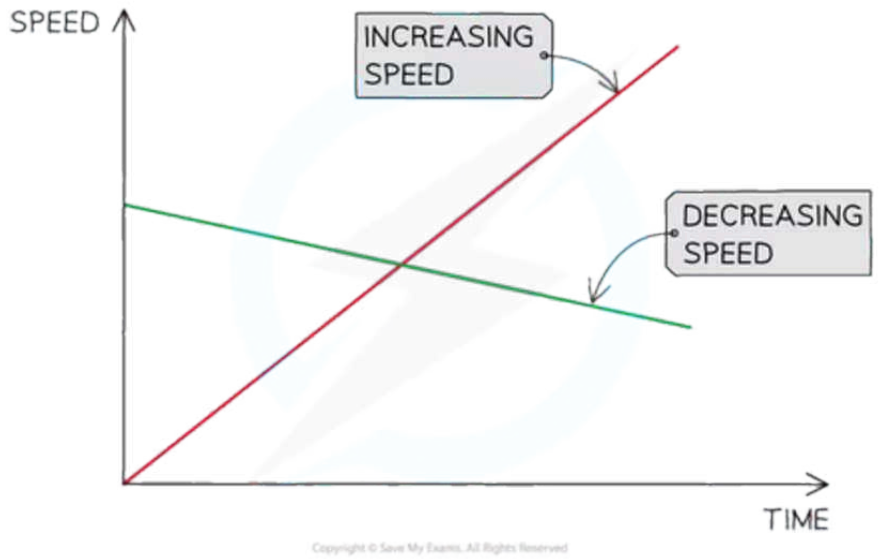
Speed-Time Graphs

Your notes

Speed-Time Graphs

- A speed-time graph shows how the speed of a moving object varies with time
 - The red line represents an object with **increasing** speed
 - The green line represents an object with **decreasing** speed

Increasing and decreasing speed



Increasing and decreasing speed represented on a speed-time graph

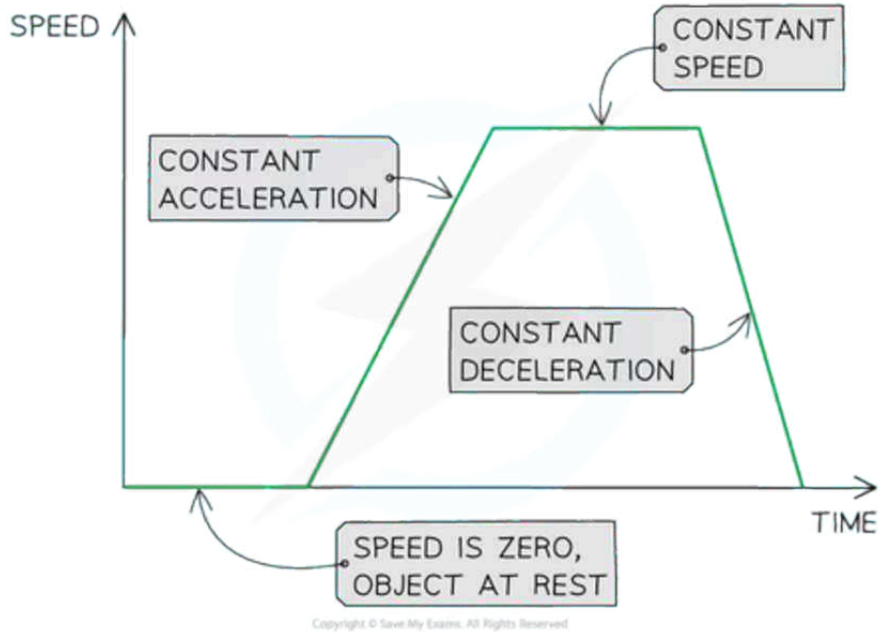
Acceleration on a Speed-Time Graph

- Speed-time graphs also show the following information:
 - If the object is moving with a **constant** acceleration or deceleration
 - The **magnitude** of the acceleration or deceleration

- A **straight line** represents **constant acceleration**
- The **slope** of the line represents the **magnitude** of acceleration
 - A **steep** slope means **large acceleration** (or deceleration) - i.e. the object's speed changes very **quickly**
 - A **gentle** slope means **small acceleration** (or deceleration) - i.e. the object's speed changes very **gradually**
 - A **flat line** means the acceleration is **zero** - i.e. the object is moving with a **constant speed**

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Acceleration, deceleration and constant speed



This image shows how to interpret the slope of a speed-time graph

Your notes

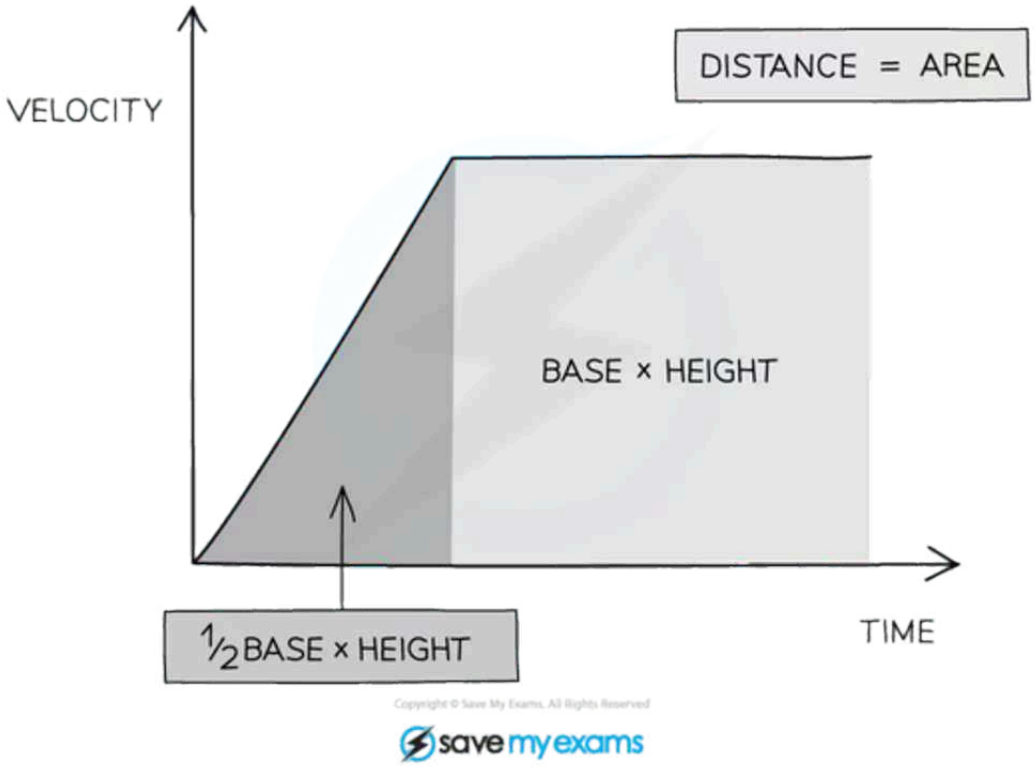
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Using Speed-Time Graphs

Your notes

- The **distance travelled** by an object can be found by determining the **area beneath the graph**

Area under a velocity-time graph



The distance travelled can be found from the area beneath the graph

- If the area beneath the graph forms a **triangle** (the object is accelerating or decelerating) then the area can be determined using the formula:

$$\text{area} = \frac{1}{2} \times \text{base} \times \text{height}$$

- If the area beneath the graph is a **rectangle** (constant velocity) then the area can be determined using the formula:

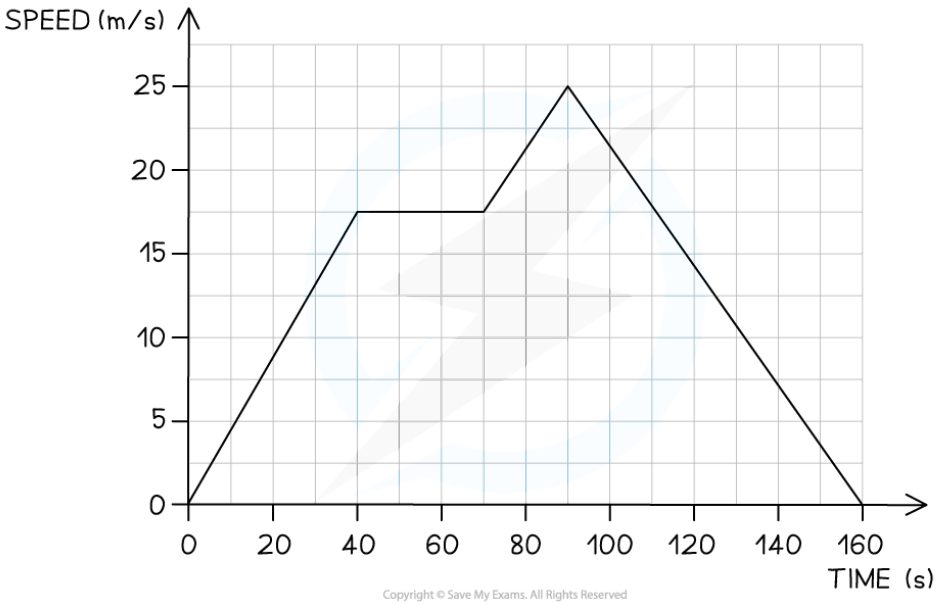
$$\text{area} = \text{base} \times \text{height}$$

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Worked example

Your notes

The speed-time graph below shows a car journey which lasts for 160 seconds.



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Calculate the total distance travelled by the car on this journey.

Answer:

Step 1: Recall that the area under a velocity-time graph represents the distance travelled

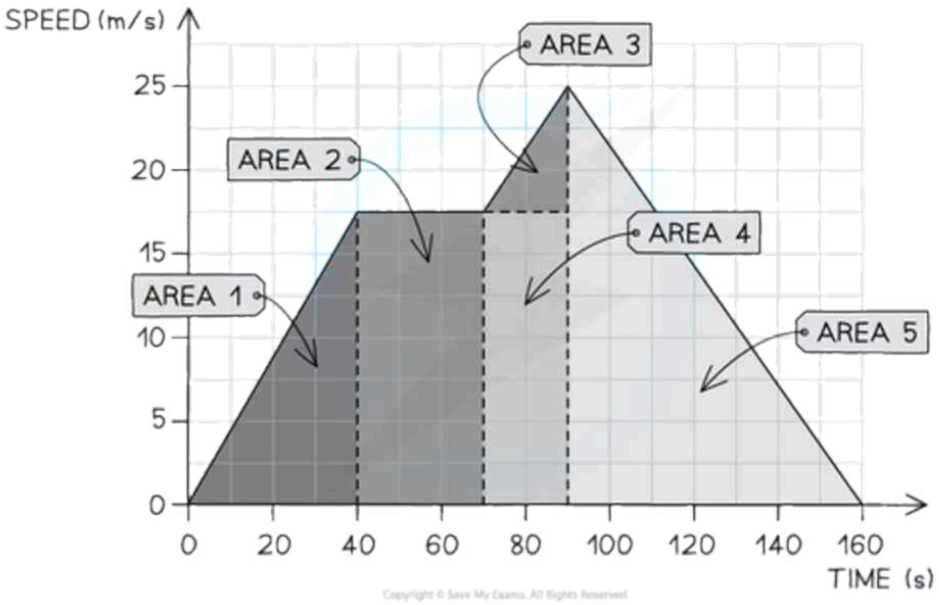
- In order to calculate the total distance travelled, the total area underneath the line must be determined

Step 2: Identify each enclosed area

- In this example, there are **five** enclosed areas under the line
- These can be labelled as areas 1, 2, 3, 4 and 5, as shown in the image below:

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Your notes



Step 3: Calculate the area of each enclosed shape under the line

- Area 1 = area of a triangle = ½ × base × height = ½ × 40 × 17.5 = **350 m**
- Area 2 = area of a rectangle = base × height = 30 × 17.5 = **525 m**
- Area 3 = area of a triangle = ½ × base × height = ½ × 20 × 7.5 = **75 m**
- Area 4 = area of a rectangle = base × height = 20 × 17.5 = **350 m**
- Area 5 = area of a triangle = ½ × base × height = ½ × 70 × 25 = **875 m**

Step 4: Calculate the total distance travelled by finding the total area under the line

- Add up each of the five areas enclosed:

$$\text{total distance} = 350 + 525 + 75 + 350 + 875$$

$$\text{total distance} = \mathbf{2175\ m}$$

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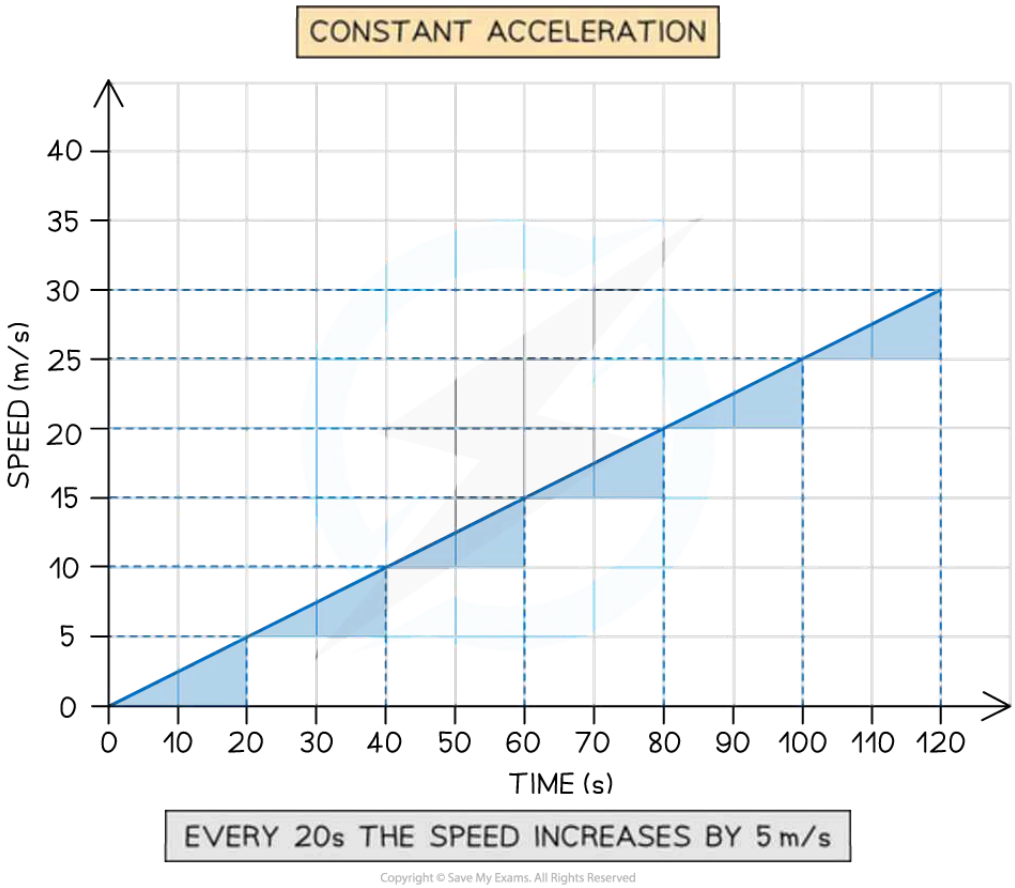
Calculating Acceleration from Speed-Time Graphs

Your notes

Interpreting Speed-Time graphs

- If there is a **change in** an object's **speed**, then it is **accelerating**
- An object may accelerate at a steady rate, this is called **constant acceleration**
 - On a speed-time graph this will be a non-horizontal **straight line**

Constant acceleration



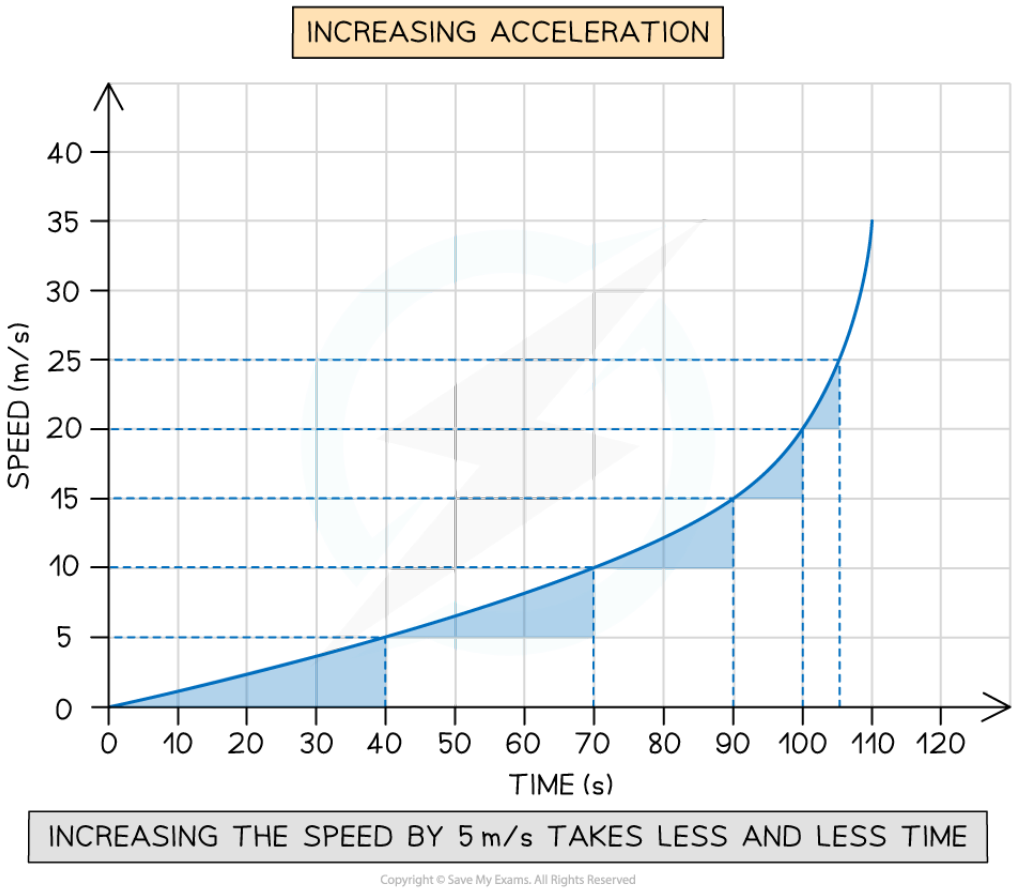
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- An object may accelerate at an **increasing rate**
 - On a speed-time graph this would be an **upward curve**

Increasing acceleration

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Your notes

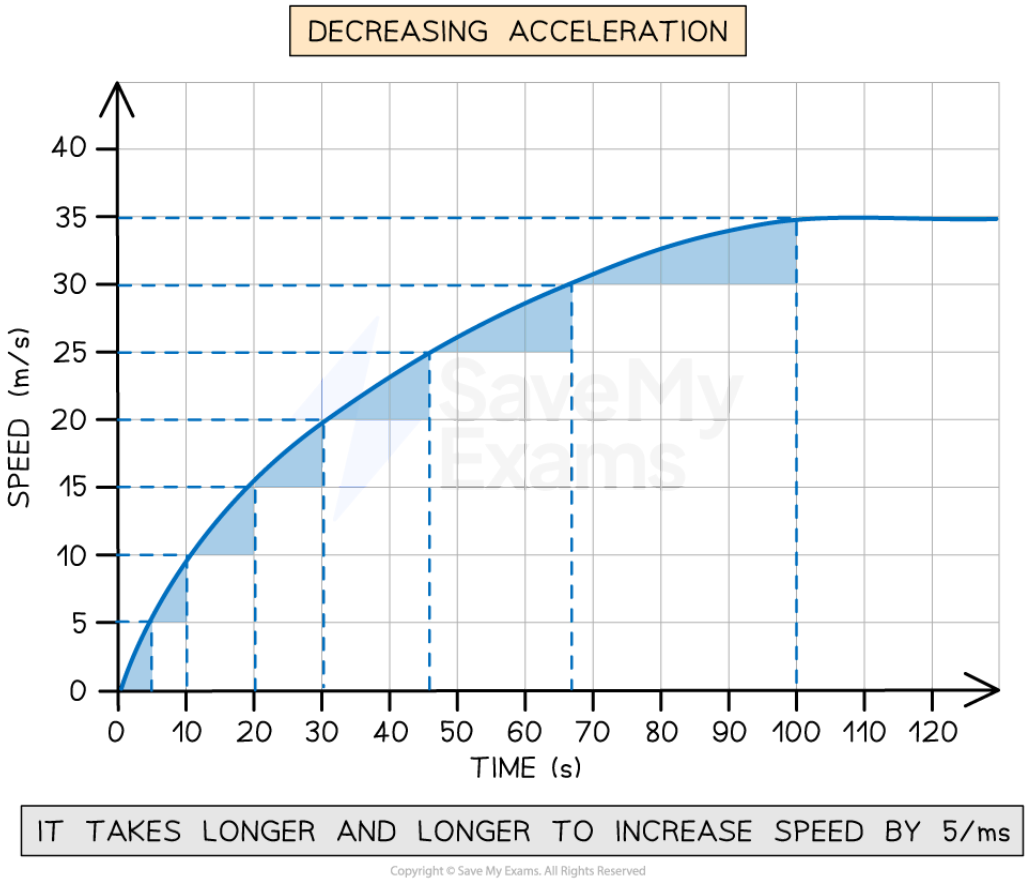


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- An object may accelerate at a **decreasing rate**
 - On a speed-time graph this would be an **upward curve** with a **decreasing gradient**

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Your notes



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- An object is said to **decelerate** if its speed is decreasing over time, i.e. its acceleration is negative
 - On a speed-time graph this would be a **downward line**
 - If the line is a non-horizontal **straight** line, deceleration is **constant**
 - If the line is a curve with an **increasing** gradient, deceleration is **increasing**
 - If the line is a curve with a **decreasing** gradient, deceleration is **decreasing**

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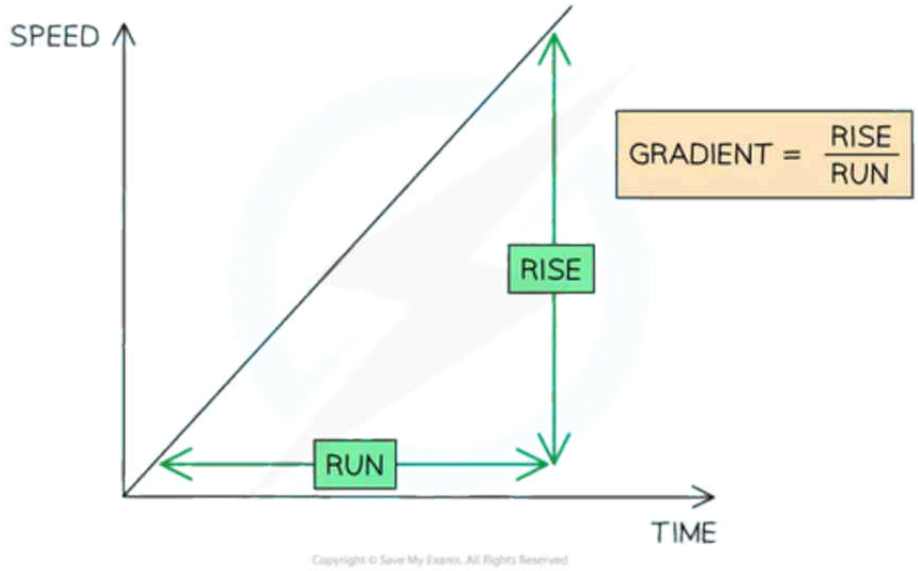
Calculating Acceleration

Your notes

- The **acceleration** of an object can be calculated from the **gradient** of a speed-time graph

$$acceleration = gradient = \frac{rise}{run}$$

Gradient of a speed-time graph



How to find the gradient of a speed-time graph

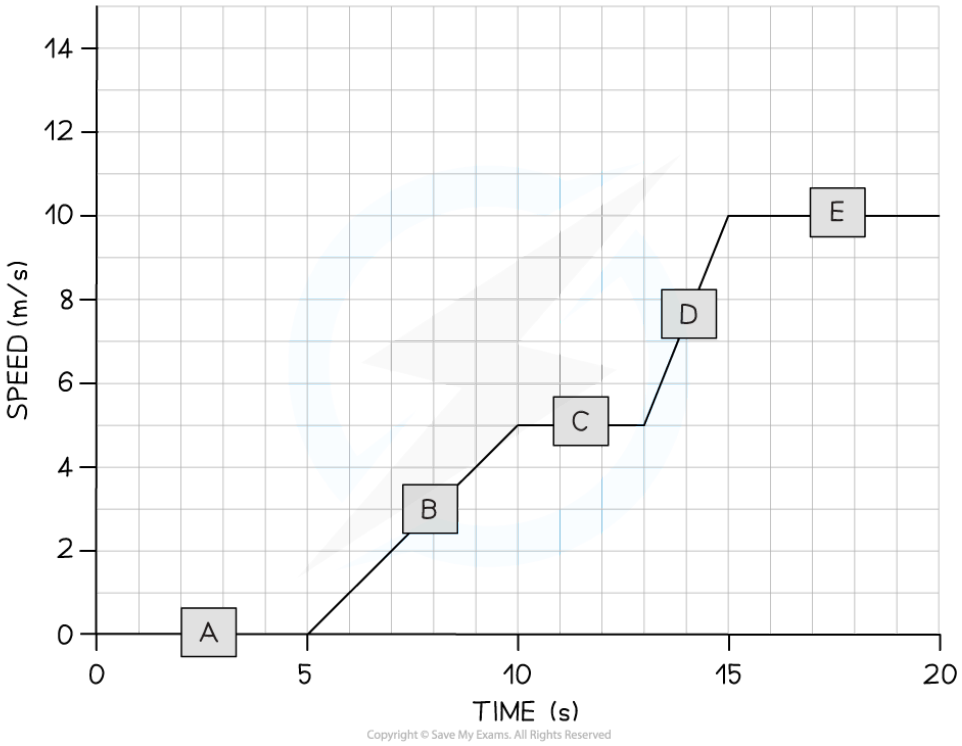
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Worked example

Your notes

Tora is training for a cycling tournament.

The speed-time graph below shows her motion as she cycles along a flat, straight road.



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(a) In which section (A, B, C, D, or E) of the speed-time graph is Tora's acceleration the largest?

(b) Calculate Tora's acceleration between 5 and 10 seconds.

Part (a)

Step 1: Recall that the slope of a speed-time graph represents the magnitude of acceleration

- The slope of a speed-time graph indicates the magnitude of acceleration
 Therefore, the only sections of the graph where Tora is accelerating is section B and section D
- Sections A, C, and E are flat – in other words, Tora is moving at a constant speed (i.e. not accelerating)

Step 2: Identify the section with the steepest slope

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- Section D of the graph has the steepest slope

 Hence, the largest acceleration is shown in section D

Your notes

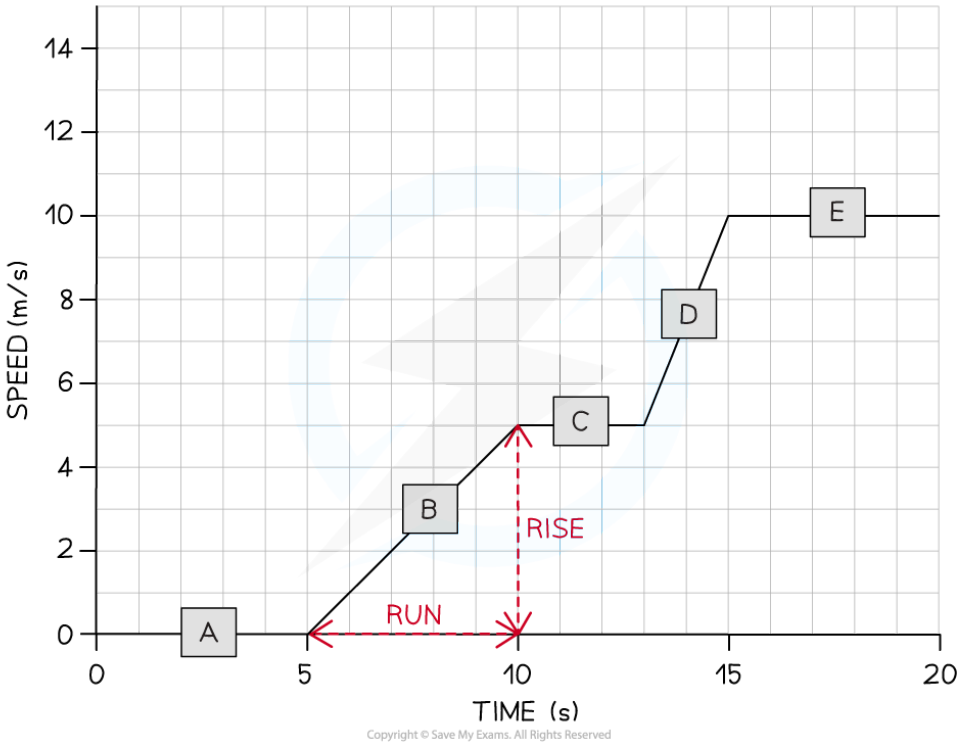
Part (b)

Step 1: Recall that the gradient of a speed-time graph gives the acceleration

- Calculating the gradient of a slope on a speed-time graph gives the acceleration for that time period

Step 2: Draw a large gradient triangle at the appropriate section of the graph

- A gradient triangle is drawn for the time period between 5 and 10 seconds below:



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Step 3: Calculate the size of the gradient and state this as the acceleration

- The acceleration is given by the gradient, which can be calculated using:

$$\text{acceleration} = \text{gradient} = 5 \div 5 = 1\ \text{m/s}^2$$

- Therefore, Tora accelerated at $1\ \text{m/s}^2$ between 5 and 10 seconds

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Exam Tip

Use the **entire slope**, where possible, to calculate the gradient. Examiners tend to award credit if they see a **large gradient triangle** used - so remember to draw 'rise' and 'run' lines directly on the graph itself!



Your notes

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Freefall

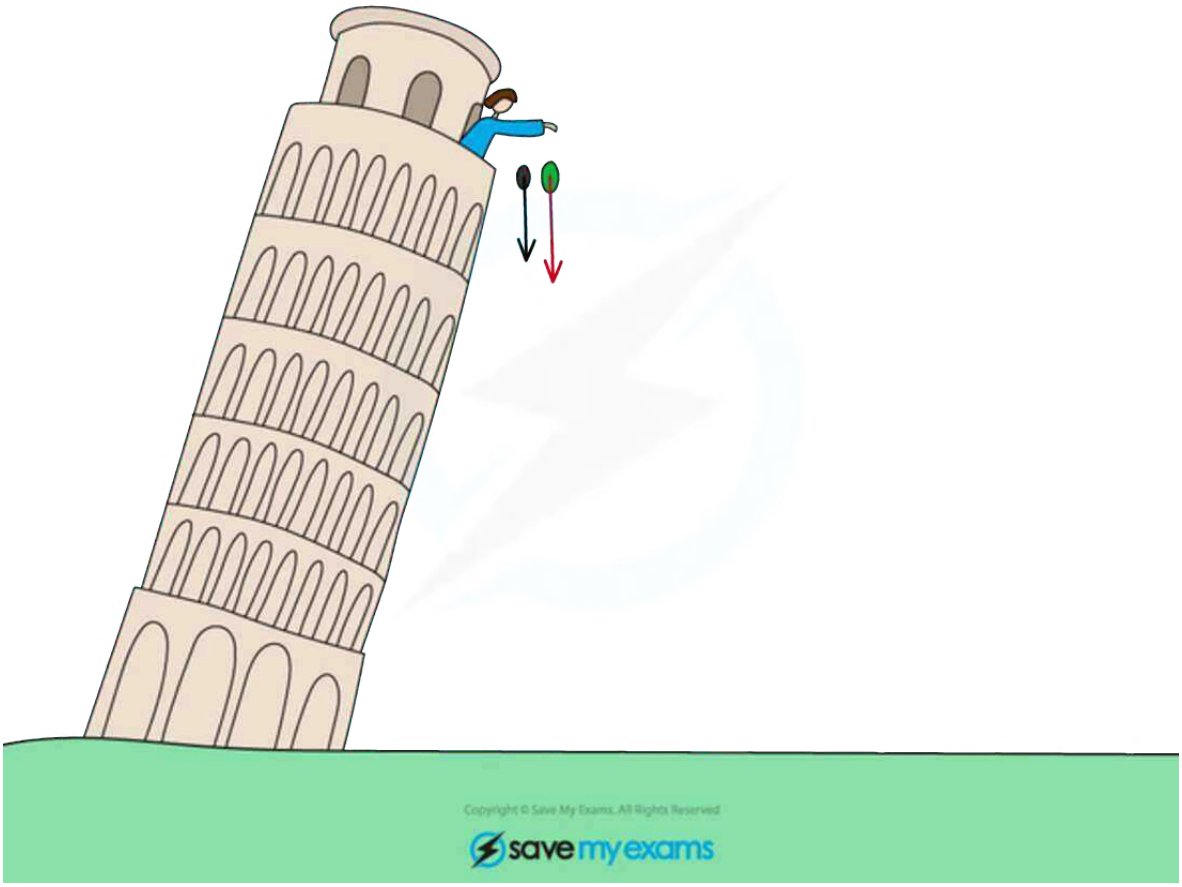
Your notes

Acceleration of Free Fall

- In the absence of **air resistance**, all objects fall with the **same acceleration**
- This is called the **acceleration of freefall** (this is also sometimes called acceleration due to gravity)

acceleration of free fall = $g = 9.81\ m/s^2$

Galileo's free fall experiment



In the absence of air resistance, Galileo discovered that all objects (near Earth's surface) fall with an acceleration of about 9.8 m/s^2

- This means that for every second an object falls, its velocity will increase by 9.8 m/s

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- The symbol ***g*** also stands for the **gravitational field strength**, and can be used to calculate the weight of an object using its mass:

weight = mass × gravitational field strength

□ = □□


Your notes

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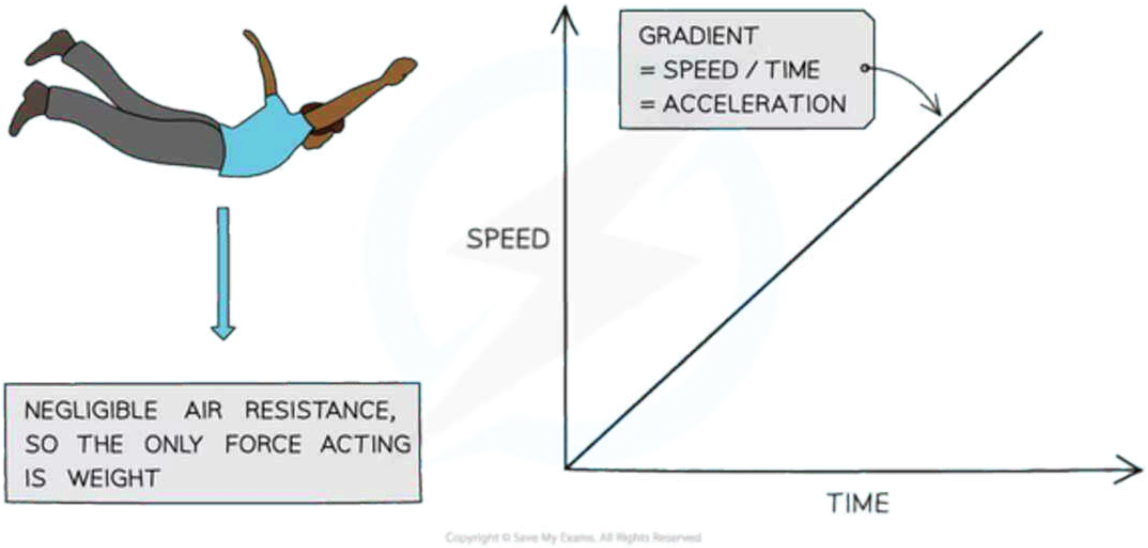
Terminal Velocity

Falling Objects without Air Resistance

Your notes

- In the **absence of air resistance**, all objects falling in a uniform gravitational field, fall with the **same acceleration**, regardless of their mass
- So long as air resistance remains insignificant, the speed of a falling object will **increase** at a **steady rate**, getting larger the longer it falls for.

Free fall with constant acceleration



In the absence of air resistance objects fall with constant acceleration

Falling Objects with Air Resistance

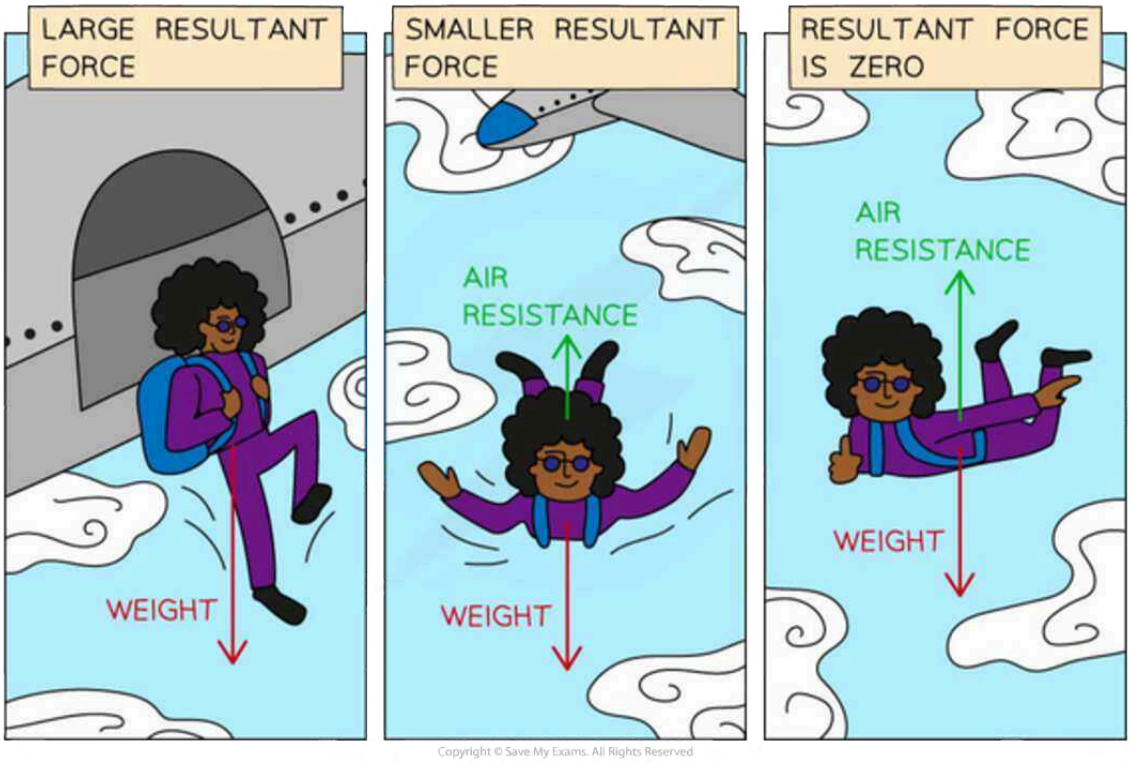
- Objects falling through fluids (fluids are liquids or gases) in a uniform gravitational field, experience **two forces**:
 - **Weight** (due to gravity)
 - **Friction** (such as air resistance)

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Your notes

- A skydiver jumping from a plane will experience:
 - A downward acting force of weight (mass × acceleration of freefall)
 - An upward acting force of air resistance (frictional forces always oppose the direction of motion)
- The force of air resistance increases with speed. This is illustrated in the image below:

Change in resultant force on a skydiver



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Debbie initially accelerates downwards due to her weight. The upwards air resistance increases as she falls until it eventually grows big enough to balance the weight force

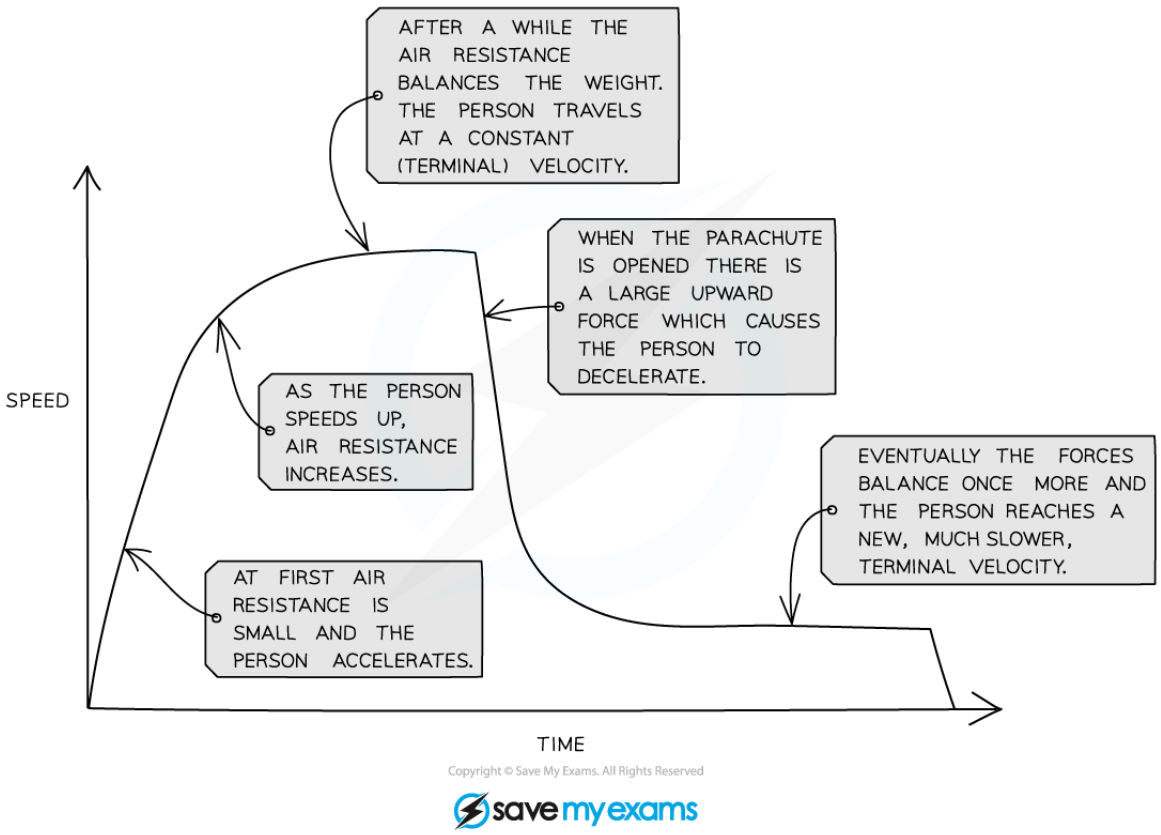
- Initially, the upwards air resistance is **very small** because the skydiver isn't falling very quickly
 - Therefore, there are **unbalanced** forces on the skydiver initially
- As the skydiver speeds up, air resistance **increases,** eventually growing large enough to **balance the downwards weight force**
- Once **air resistance equals weight,** the forces are **balanced**
 - This means there is no longer any **resultant force**
- Therefore, the skydiver's acceleration is **zero** - they now travel at a **constant** speed
- This speed is called their **terminal velocity**
- When the skydiver opens the parachute, the **air resistance increases**

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- This is due to the increased surface area of the parachute opening
- The upward force of air resistance on the skydiver increases, **slowing the acceleration** of the skydivers fall
 - The skydiver **decelerates**
- Eventually, the **forces balance** out again, and a new **slower terminal velocity** is reached

Your notes

Speed-time graph for a skydiver



Graph showing how the velocity of a skydiver changes during the descent

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Worked example

A small object falls out of an aircraft. Choose words from the list to complete the sentences below:

Friction **Gravitational field strength** **Air pressure**

Accelerates **Falls at a steady speed** **Slows down**

(a) The weight of an object is the product of the object's mass and the _____.

(b) When an object falls, initially it _____.

(c) As the object falls faster, the force of _____ acting upon the object increases.

(d) Eventually the object _____ when the force of friction equals the force of weight acting on it.

Answer:

Part (a)

- The weight of an object is the product of the object's mass and the **gravitational field strength**.
 - The weight force is due to the Earth's gravitational pull on the object's mass as it falls through a uniform gravitational field

Part (b)

- When an object falls, initially it **accelerates**
- The **resultant force** on the object is **very large** initially, so it accelerates
- This is because there is a **large unbalanced force** downwards (its weight) - the upward force of air resistance is very small to begin with

Part (c)

- As the object falls faster, the force of **friction** acting upon the object increases.
- The force of **air resistance** is due to **friction** between the object's motion and **collisions with air particles**
- Collisions with air particles slow the object down, so air itself produces a **frictional force**, called air resistance (sometimes called **drag**)

Part (d)

Your notes

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- Eventually the object **falls at a steady speed** when the force of friction equals the force of weight acting on it.
- When the upwards **air resistance** increases enough to **balance** the downwards **weight** force, the resultant force on the object is **zero**
- This means the object isn't accelerating - rather, it is moving at a **steady** (terminal) **speed**


Your notes

Exam Tip

The force of gravity on an object with mass is called **weight**. If asked to name this force make sure you use this word: Don't refer to it as "gravity" as this term could also mean gravitational field strength and so would probably be marked wrong.

Likewise, remember to identify **air resistance** as the upwards force on a falling object. This force **gets larger** as the object speeds up, but the weight of the object stays constant. Don't confuse 'air resistance' with 'air pressure' - these are two different concepts!

Exam questions about terminal velocity tend to involve the motion of skydivers as they fall

A common misconception is that skydivers move upwards when their parachutes are deployed - however, this is not the case, they are in fact **decelerating** to a lower terminal velocity

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Cambridge O Level Physics

Your notes

1.3 Mass & Weight

Contents

- Mass & Weight
- Measuring Mass & Weight

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Mass & Weight


Your notes

Mass

- Mass is a measure of the quantity of **matter** in an object at rest relative to the observer
 - Mass is a **scalar** quantity
 - The SI unit for mass is the **kilogram** (kg)
- Consequently, mass is the property of an object that resists change in motion
 - The greater the mass of an object, the more difficult it is to speed it up, slow it down, or change its direction
- A mass may sometimes be given in **grams** (g)
 - 1000 g = 1 kg
 - 1 g = 0.001 kg

Worked example

An object has a mass of 2.7 kg.

State the number of grams in 2.7 kg.

Answer:

Step 1: State the conversion between g and kg

- 1 kg = 1000 g

Step 2: Convert 2.7 kg into g

- 2.7 kg = 2.7 × 1000 = 2700 g

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Weight

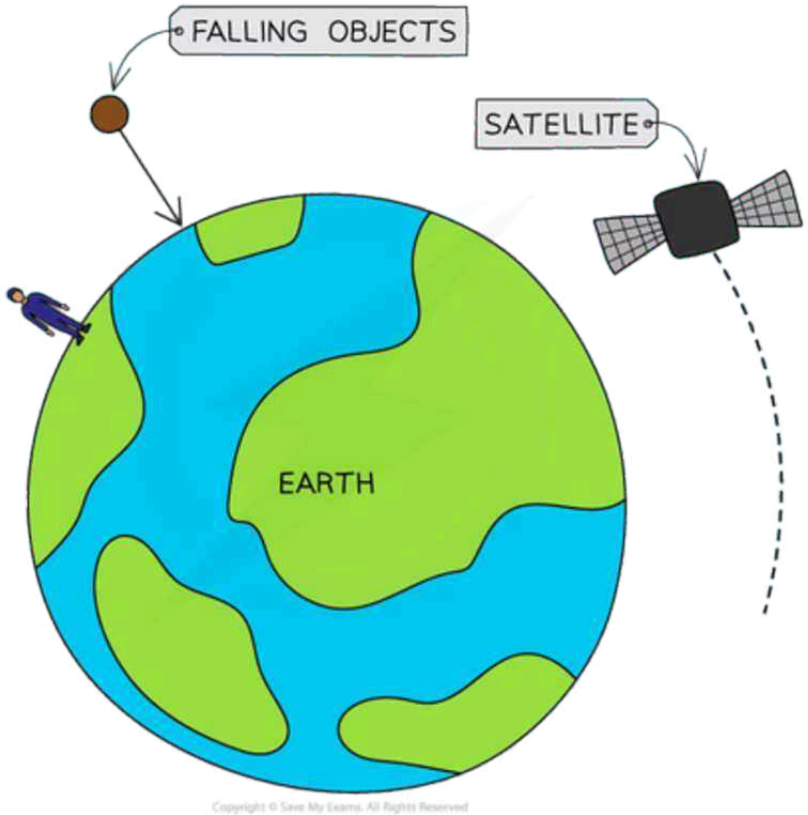
Your notes

- Weight is a gravitational **force** on an object with mass
 - Weight is a force, so it is a **vector** quantity
 - The SI units for force are **newtons** (N)
- Weight is the effect of a **gravitational field** on a mass
- Weight is defined as:

The force acting on an object due to gravitational attraction

- Planets have strong gravitational fields
 - Hence, they attract nearby masses with a strong gravitational force
- Because of weight:
 - Objects stay firmly on the ground
 - Objects will always fall to the ground
 - Satellites are kept in orbit

Gravitational forces around Earth



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Some of the phenomena associated with gravitational attraction and the weight force

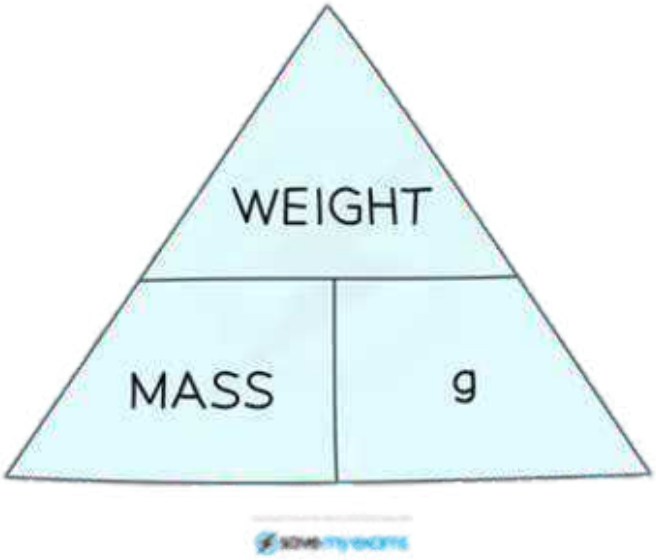
Your notes

- The weight of a body is equal to the product of its mass (m) and the acceleration of free fall (g)

□ = □□

- Where:
 - W = weight (N)
 - m = mass (kg)
 - g = gravitational field strength (m/s^2 or N/kg)
- You can rearrange this equation with the help of the formula triangle:

Weight equation triangle



Weight, mass and gravitational field strength equation triangle

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Gravitational Field Strength

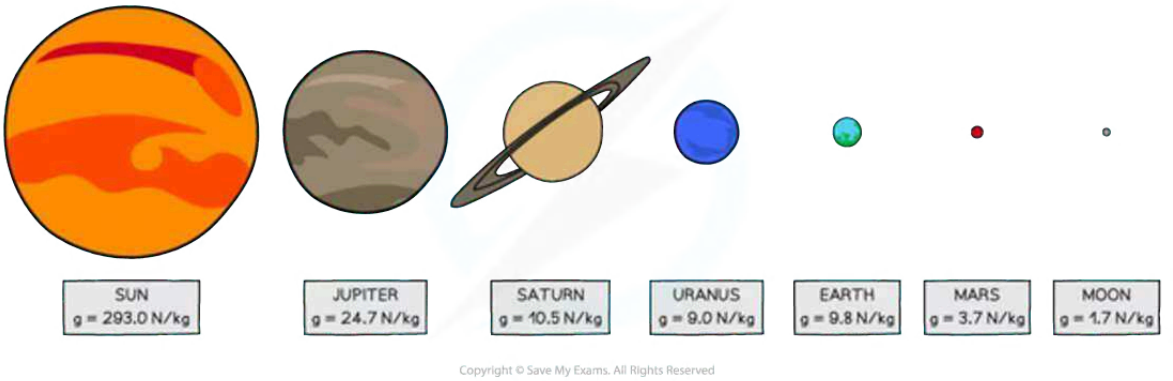
Your notes

- **Gravitational field strength** is defined as:

The force per unit mass acting on an object in a gravitational field

- On Earth, this is equal to **9.8 N/kg**
- Gravitational field strength is also known as acceleration of free fall, or acceleration due to gravity
 - In this context the units are m/s^2
- The value of *g* (gravitational field strength) varies from planet to planet depending on their mass and radius
- A few examples of varying gravitational field strength are shown below:

g on other planets



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Gravitational field strength of the planets in our solar system

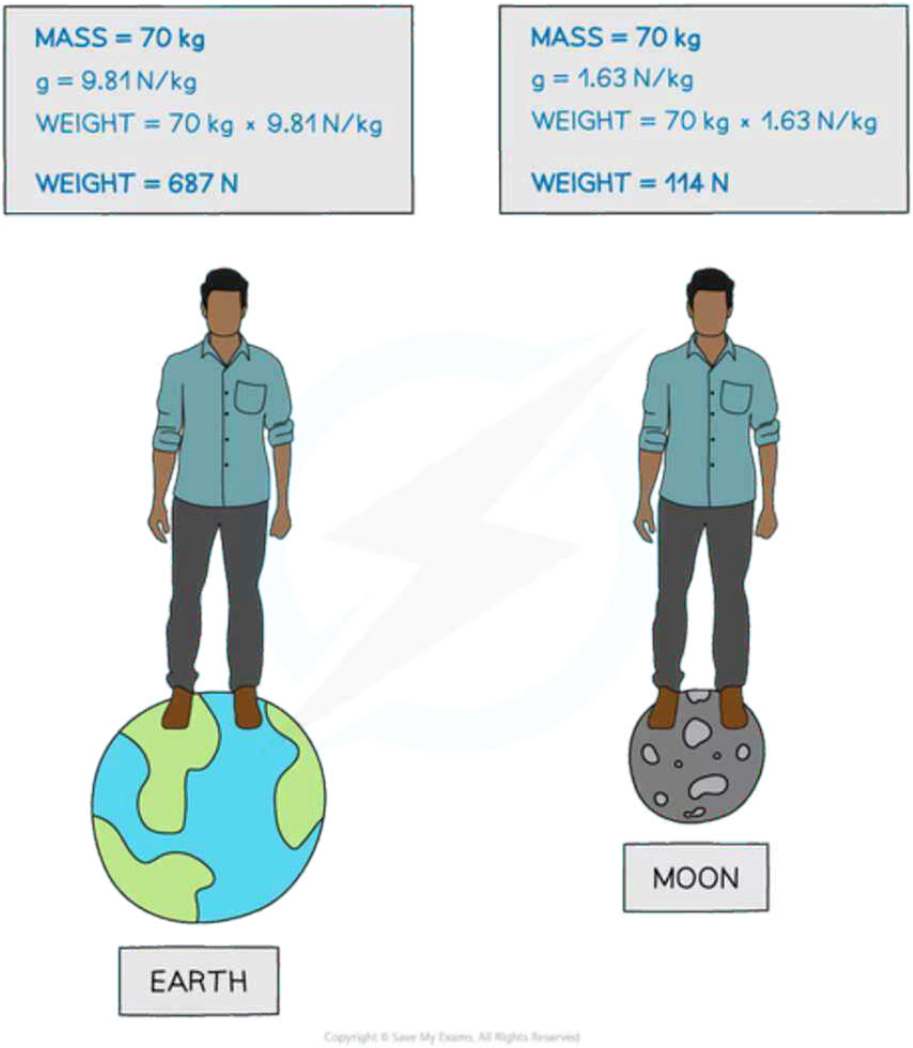
Mass vs. Weight

- An object's mass always remains the same, however, its weight will differ depending on the strength of the gravitational field on different planets
- For example, the gravitational field strength on the Moon is **1.63 N/kg**, meaning an object's weight will be about **6 times** less than on Earth

Mass vs. weight on the Earth and Moon

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Your notes



On the moon, your mass will stay the same but your weight will be much lower

Exam Tip

You won't be expected the learn the **exact** value of g (9.81 N/kg), but you will be expected to remember that ***g* = 9.8 N/kg** and use it in calculations

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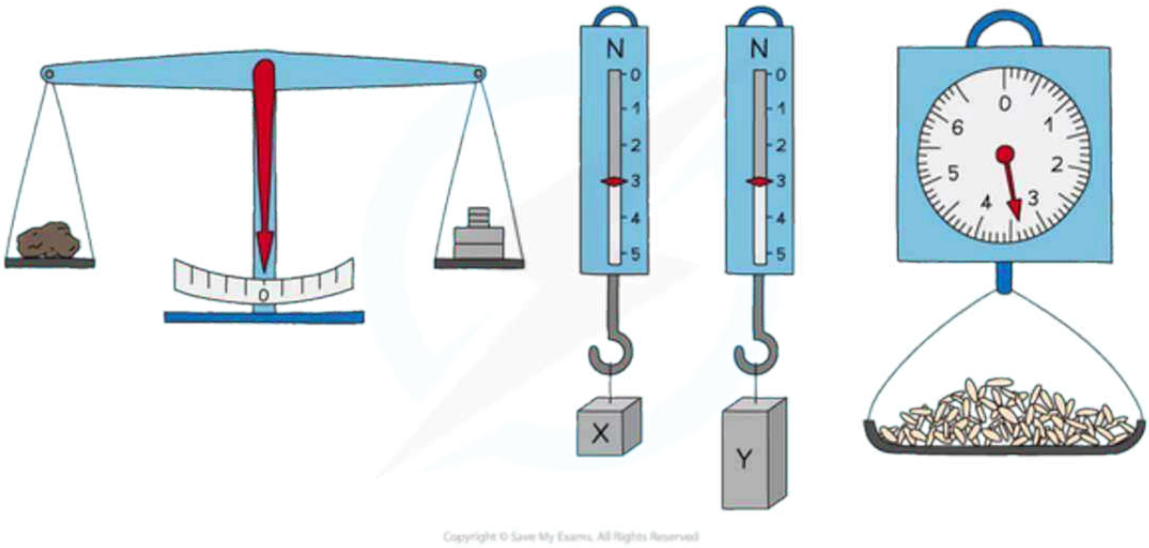
Using a Balance

Your notes

- The weight of two objects can be compared using a balance
 - Because the gravitational field strength is constant everywhere on Earth, this also allows us to measure the mass of an object

□ = □

Using a balance



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A balance can be used to compare two different weights

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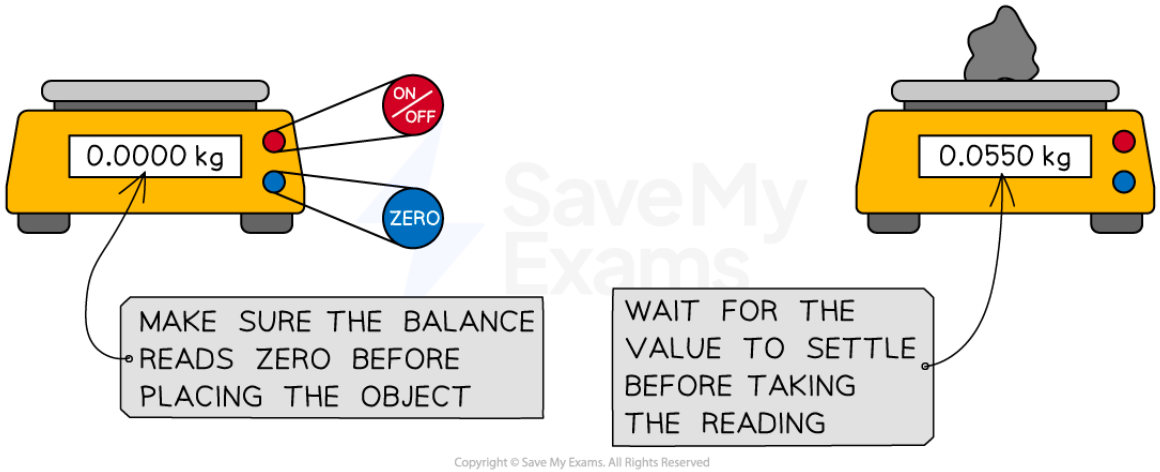
Measuring Mass & Weight

Your notes

Measuring Mass & Weight

Measuring the Mass of an Object with a Digital Balance

Using a Digital Balance to Measure the Mass of an object



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The digital balance must read zero before the object is added, then wait until the reading has settled before taking the measurement

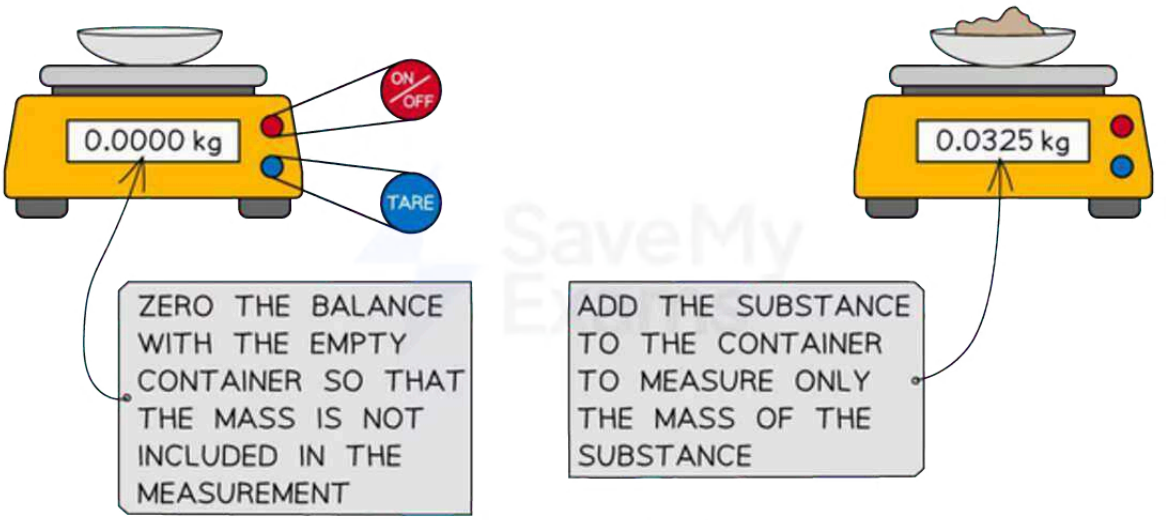
1. Turn on the digital balance by pressing the power button
2. Wait for the value on the display to show **zero** (if it does not settle on zero, press and hold the zero button)
3. Place the object on the digital balance
4. Wait for the reading to **stop fluctuating**
5. Record the measurement
6. Remove the object and wait for the display to read **zero** again before placing another object on the balance

Measuring the Mass of a Substance – Zero Method

Using The Zero Method to Measure the Mass of a Substance

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The empty container is placed on the digital scale and then the scale is zeroed so that the mass of the container is not included in the measurement

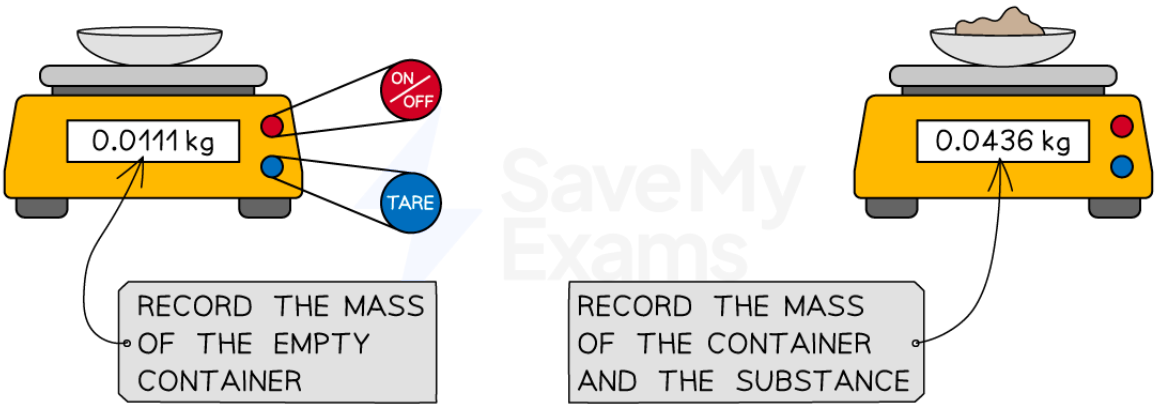
1. Turn on the digital balance by pressing the power button
2. Wait for the value on the display to show **zero**
3. Place the **empty** container on the digital balance
4. Wait for the reading to **stop fluctuating**
5. Hold the **zero** button (sometimes called the **tare** button) until the display reads zero
6. Add the **substance** to the container
7. Wait for the reading to **stop fluctuating**
8. Record the measurement
9. Remove the container and wait for the display to read **zero** again before placing another object on the balance

Measuring the Mass of a Substance – Subtraction Method

Using The Subtraction Method to Determine the Mass of a Substance

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The mass of the empty container is recorded and then subtracted from the combined mass of the container and the substance

1. Turn on the digital balance by pressing the power button
2. Wait for the value on the display to show **zero**
3. Place the **empty** container on the digital balance
4. Wait for the reading to **stop fluctuating**
5. Record the measurement of the **container only**
6. Remove the container and wait for the display to read **zero** again
7. Place the container with the **substance** inside on the digital balance
8. Wait for the reading to **stop fluctuating**
9. Record the measurement of the **substance + container**
10. **Subtract** the mass of the container only from the mass of the substance + container

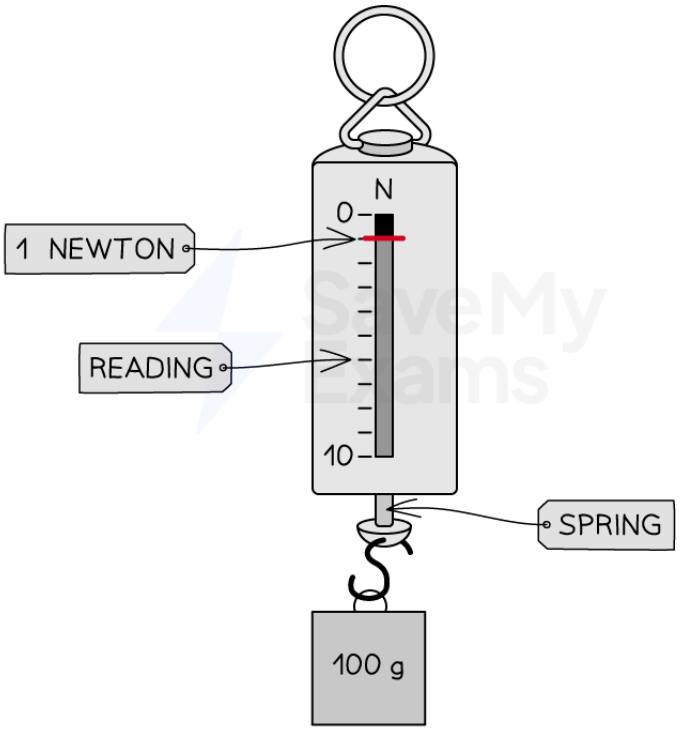
$$\text{mass of substance} = (\text{mass of substance} + \text{mass of container}) - (\text{mass of container})$$

Measuring Weight Using a Force Meter

Using a Force Meter to Measure the Weight of an Object

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The object is suspended from the force meter to give a reading of the object's weight. The reading should be taken from eye level to avoid parallax error

1. Hook the object onto the **newton meter** or **force meter** (these are two different names for the **same** device)
2. Carefully raise the object and newton meter so that the object is **freely hanging**
3. Wait for the object for **still** and for the reading to **steady**
4. Take the reading from **eye level** to ensure accuracy

- **Mass** can also be determined using this measurement of **weight**
 - $W = mg$
 - Therefore, $m = \frac{W}{g}$

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Cambridge O Level Physics

Your notes

1.4 Density

Contents

- Density
- Measuring Density

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Density

Your notes

Density

- Density is defined as:

The mass per unit volume of a material

- Objects made from **low density** materials typically have a **low mass**
- Similarly sized objects made from **high density** materials have a **high mass**
 - For example, a bag full of feathers is far lighter compared to a similar bag full of metal
 - Or another example, a balloon is less dense than a small bar of lead despite occupying a larger volume

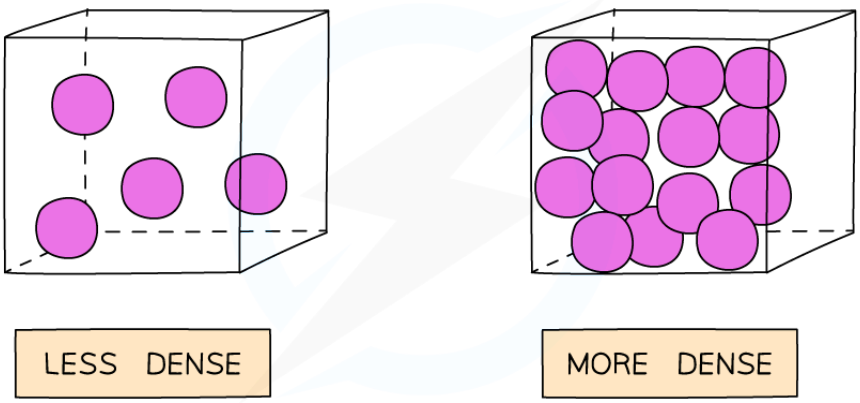
- Density is related to mass and volume by the following equation:

$$\rho = \frac{m}{V}$$

- Where:
 - ρ = density (kg/m^3)
 - m = mass (kg)
 - V = volume (m^3)

- Gases, for examples, are less dense than solids because the molecules are more spread out (same mass, over a larger volume)

Gases vs. liquids density



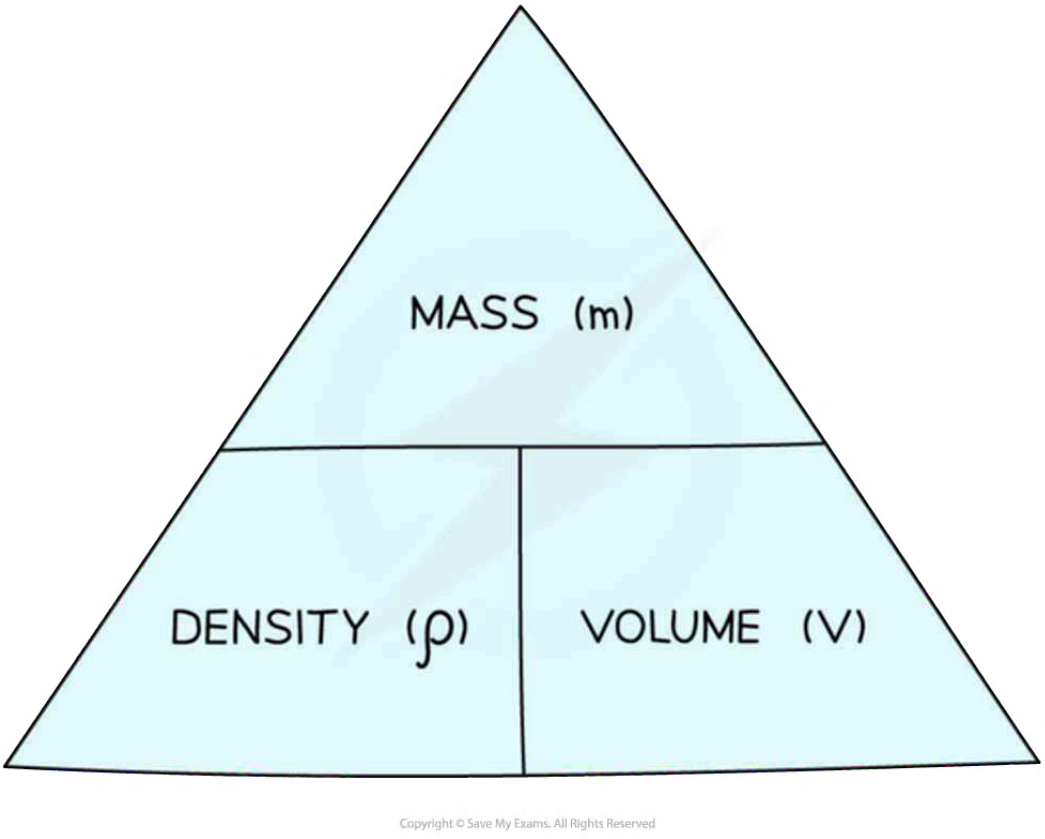
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Gases are less dense than solids

- This equation can be rearranged with the help of the formula triangle:

Density equation triangle



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Density, mass, volume equation triangle

- The units of density depend on what units are used for mass and volume:
 - If the mass is measured in g and volume in cm^3, then the density will be in g/cm^3
 - If the mass is measured in kg and volume in m^3, then the density will be in kg/m^3
- This table gives some examples of densities on common materials
 - If a material is more dense than water (1000 kg/m^3), then it will sink

Approximate Densities of Materials Table

Material	Approximate Density (kg/m^3)

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Air	1.3
Wood	300 - 800 (depending on species)
Water	1000
Granite	2700
Lead	11 300

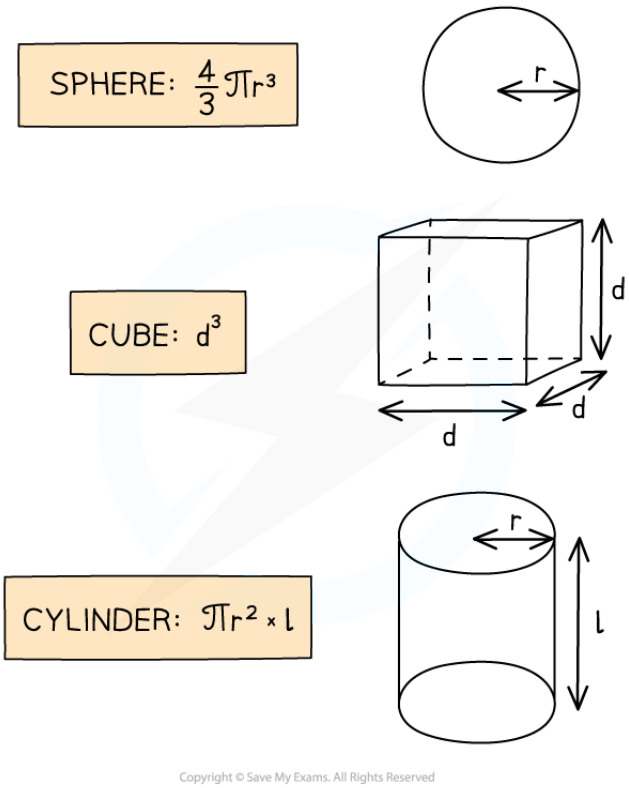
- The volume of an object may not always be given directly, but can be calculated with the appropriate equation depending on the object's shape

Volumes of common 3D shapes


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Your notes



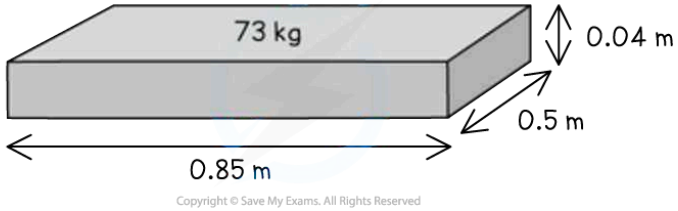
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The volumes depends on the shape

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Worked example

A paving slab has a mass of 73 kg and dimensions 0.04 m × 0.5 m × 0.85 m.



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Calculate the density, in kg/m^3, of the material from which the paving slab is made.

Answer:

Step 1: List the known quantities

- Mass of slab, m = 73 kg
- Volume of slab, V = 0.04 m × 0.5 m × 0.85 m = 0.017 m^3

Step 2: Write out the equation for density

$$\rho = \frac{m}{V}$$

Step 3: Substitute in values

$$\rho = 73 \div 0.017 = 4294 \text{ kg/m}^3$$

Step 4: Round the answer to two significant figures

$$\rho = 4300 \text{ kg/m}^3$$

Exam Tip

Make sure you are comfortable converting between units such as metres (m) and centimetres (cm) or grams (g) and kilograms (kg).

- When converting a **larger** unit to a **smaller** one, you **multiply (×)**
 - E.g. 125 m = 125 × 100 = 12 500 cm
- When you convert a **smaller** unit to a **larger** one, you **divide (÷)**
 - E.g. 5 g = 5 ÷ 1000 = 0.005 or 5 × 10^{-3} kg

Your notes

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Measuring Density

Your notes

Measuring Density

Equipment List

Apparatus	Purpose
Regular and irregular shaped objects	To determine the density of
A suitable liquid e.g. water	To submerge the object in and measure the displacement
30 cm ruler	Used to measure objects up to 30 cm in length
Vernier caliper	Used to measure the diameter of objects
Micrometer	To measure small objects (up to around 3 cm)
Digital balance	To measure the mass of objects
Displacement (or eureka) can	To place the water and object in
Measuring cylinder	To measure the volume of the displaced water

- Resolution of measuring equipment:
 - 30 cm ruler = 1 mm
 - Vernier calipers = 0.01 mm
 - Micrometer = 0.001 mm
 - Digital balance = 0.01 g

Experiment 1: Measuring the Density of Regularly Shaped Objects

- The aim of this experiment is to determine the densities of regular objects by using measurements of their dimensions

Variables:

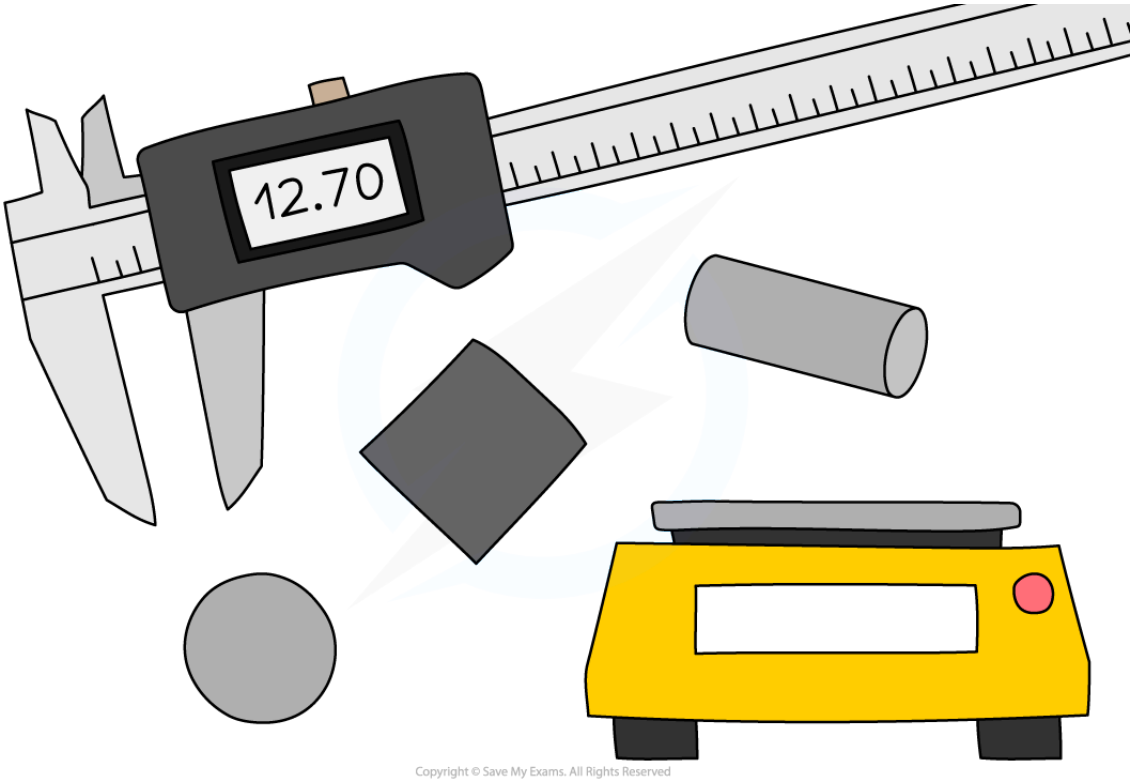
- Independent variable = Type of shape / volume
- Dependent variable = Mass of the object

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Method

Your notes

Vernier Caliper & Digital Balance



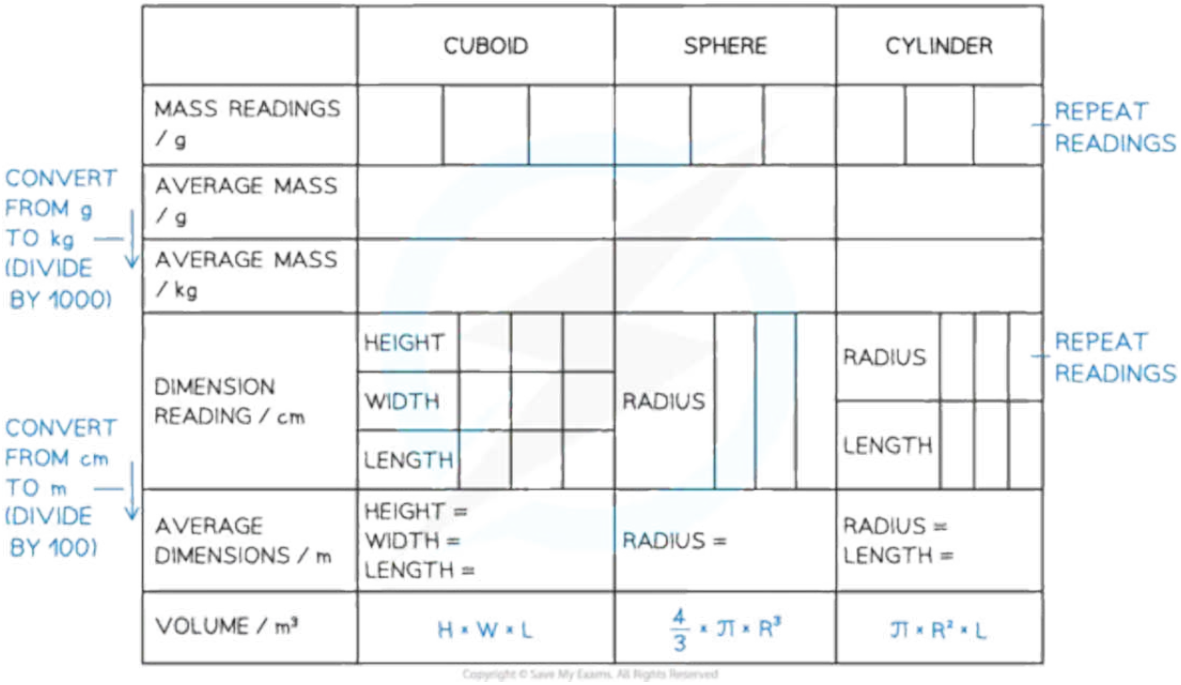
Vernier calipers are used to measure the diameter of a cylindrical shaped object to calculate its volume, and the digital scales are used to measure the object's mass

1. Place the object on a digital balance and note down its mass
2. Use either the ruler, Vernier calipers or micrometer to measure the object's dimensions (width, height, length, radius) – the apparatus will depend on the size of the object
3. Repeat these measurements and take an average of these readings before calculating the density

- An example of a results table might look like this:

Results Table

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A results table should include areas to record all the relevant data i.e. measurements and calculations

Analysis of Results

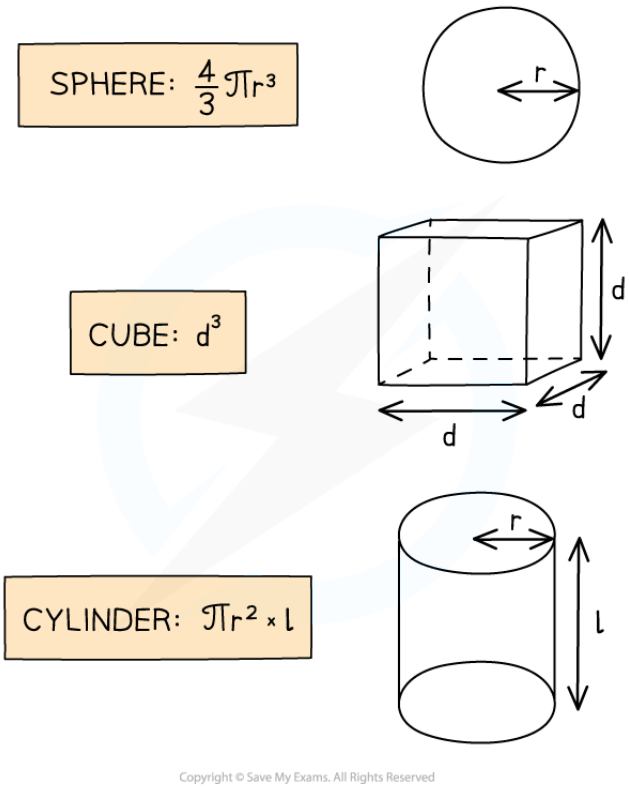
- Calculate the volume of the object depending on whether it is a cube, sphere, cylinder (or other regular shape)

Volume Formulae for Common Shapes

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Your notes



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Calculating the volume of an object depends on its shape

- Remember to convert from **centimetres (cm)** to **metres (m)** by dividing by 100

1 cm = 0.01 m

50 cm = 0.5 m

- Using the mass and volume, the density of each can be calculated using the equation:

$$\rho = \frac{m}{V}$$

- Where:
 - ρ = density in kilogram per metres cubed (kg/m^3)
 - m = mass in kilograms (kg)
 - V = volume in metres cubed (m^3)

Experiment 2: Measuring the Density of Irregularly Shaped Objects

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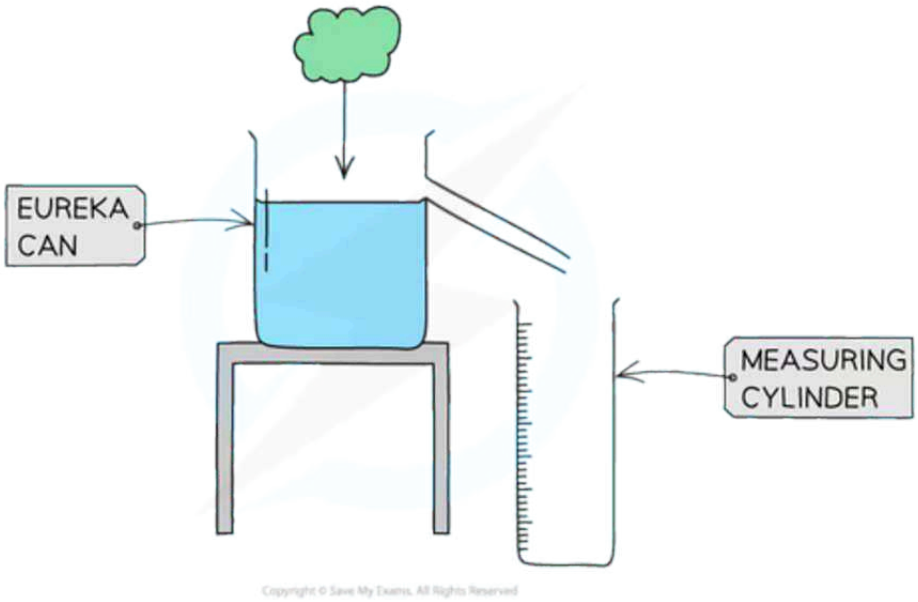
- The aim of this experiment is to determine the densities of irregular objects using a displacement technique

Variables:

- Independent variable = Different irregular shapes / mass
- Dependent variable = Volume of displaced water

Method

Apparatus for Measuring the Volume of Irregularly Shaped Objects



The volume of an irregularly shaped object can be found using the displacement of water. The object's mass can then be measured and these values used to calculate the object's density

1. Place the object on a digital balance and note down its mass
2. Fill the eureka can with water up to a point just below the spout
3. Place an empty measuring cylinder below its spout
4. Carefully lower the object into the eureka can
5. Measure the volume of the displaced water in the measuring cylinder
6. Repeat these measurements and take an average before calculating the density

- Alternatively, the object can be placed in a measuring cylinder containing a known volume of liquid, and the change in volume then measured

Your notes

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- Once the mass and volume of the shape is known, its density can be calculated
- An example of a results table might look like this:

Your notes

Results Table

OBJECT	MASS OF OBJECT / g			AVERAGE MASS / kg	VOLUME OF WATER DISPLACED / m^3			AVERAGE VOLUME OF WATER DISPLACED / m^3
	1	2	3		1	2	3	
1								
2								
3								

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A results table should contain areas for all the required data in a logical format

Analysis of Results

- The volume of the water displaced is equal to the volume of the object
- Once the mass and volume of the shape are known, the density can be calculated using:

$$\rho = \frac{m}{V}$$

Experiment 3: Measuring Density of Liquids

- The aim of this experiment is to determine the density of a liquid by finding a difference in its mass

Variables:

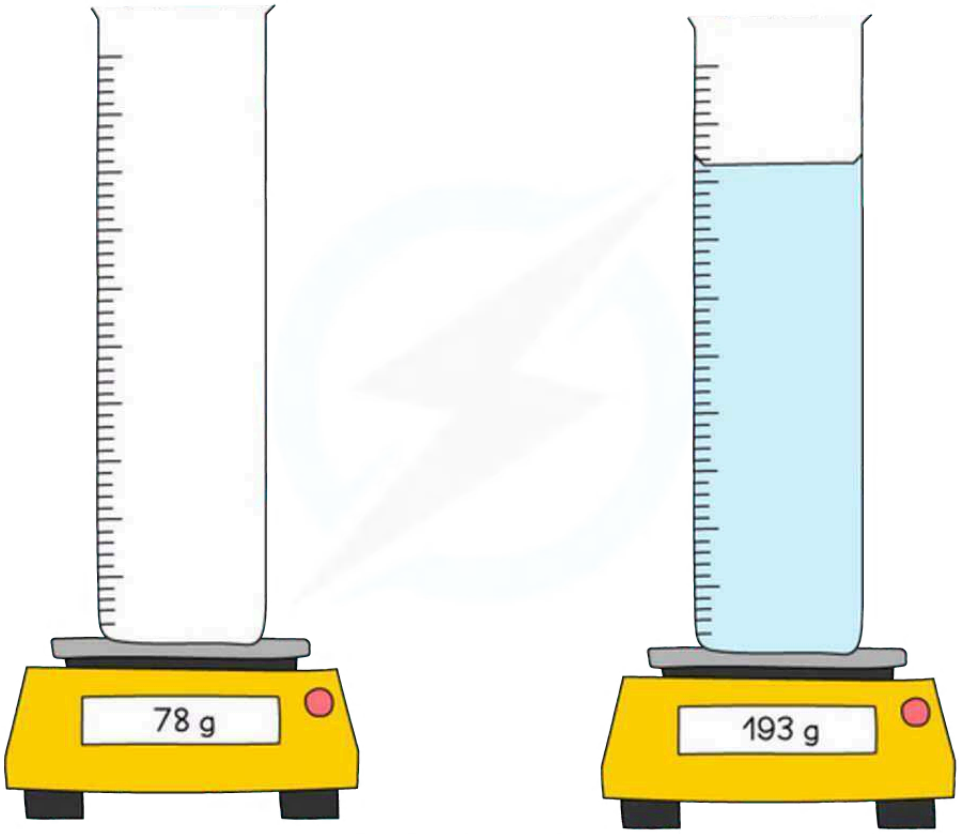
- Independent variable = Volume of water added
- Dependent variable = Mass of cylinder

Method

Measuring the Mass of Liquid in a Container

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Mass of liquid = (mass of liquid + container) – (mass of container)

1. Place an empty measuring cylinder on a digital balance and note down the mass
2. Fill the cylinder with the liquid and note down the volume
3. Note down the new reading on the digital balance
4. Repeat these measurements and take an average before calculating the density

- An example of a results table might look like this:

Results Table

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Your notes

MASS OF CYLINDER BEFORE / g			AVERAGE MASS / kg	VOLUME OF WATER ADDED / m^3	MASS OF CYLINDER WITH WATER / g			AVERAGE MASS OF CYLINDER WITH WATER / kg
1	2	3			1	2	3	

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A results table should have spaces for all the measurements and calculations required

Analysis of Results

- Find the mass of the liquid by subtracting the final reading from the original reading

Mass of liquid = Mass of cylinder with water – mass of cylinder

- Remember to convert between **grams (g)** and **kilograms (kg)** by dividing by 1000

1 g = 0.001 kg

78 g = 0.078 kg

- Once the mass and volume of the liquid are known, the density can be calculated using the equation:

$$\rho = \frac{m}{V}$$

Evaluating the Experiments

Systematic Errors:

- Ensure the digital balance is set to zero before taking measurements of mass
 - This includes when measuring the density of the liquid – remove the measuring cylinder and zero the balance before adding the liquid

Random Errors:

- A main cause of error in this experiment is in the measurements of length
 - Ensure to take repeat readings and calculate an average to keep this error to a minimum

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- Place the irregular object in the displacement can carefully, as dropping it from a height might cause water to splash which will lead to an incorrect volume reading


Your notes

Safety Considerations

- There is a lot of glassware in this experiment, ensure this is handled carefully
- Water should not be poured into the measuring cylinder when it is on the electric balance
 - This could lead to electric shock
- Make sure to stand up during the whole experiment, to react quickly to any spills

Exam Tip

There is a lot of information to take in here! When writing about experiments, a good sequence is as follows:

- If you need to use an equation to calculate something, start off by giving it as this will give you some hints about what you need to mention later
- List the apparatus that you need
- State what measurements you need to make (your equation will give you some hints) and how you will measure them
- Finally, state that you will repeat each measurement several times and take averages

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Cambridge O Level Physics

Your notes

1.5 Forces

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- Newton's Second Law
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- Equilibrium
- Centre of Gravity
- Investigating Centre of Gravity

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Resultant Forces

Your notes

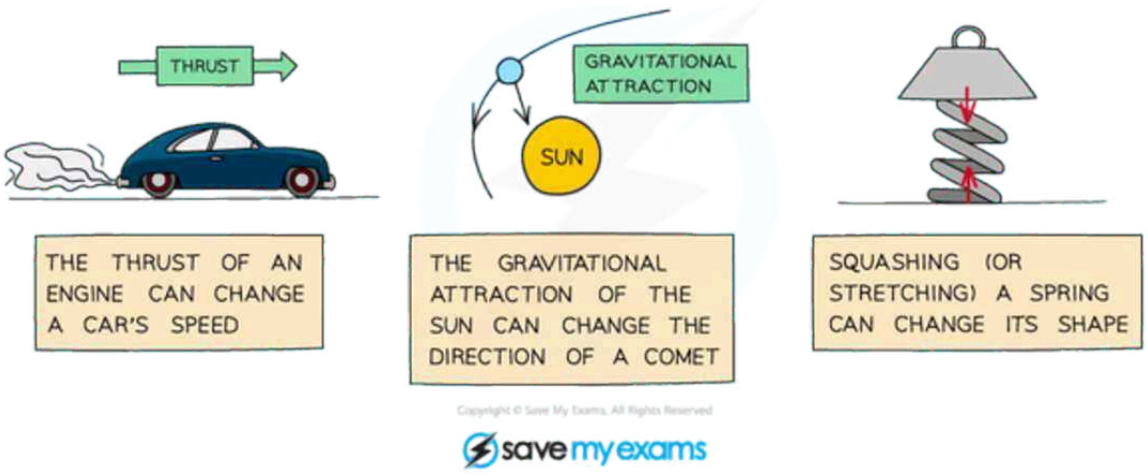
Types of Force

- A force is defined as:

A push or a pull that acts on an object due to the interaction with another object

- Forces can affect bodies in a variety of ways:
 - Changes in **speed**: forces can cause bodies to speed up or slow down
 - Changes in **direction**: forces can cause bodies to change their direction of travel
 - Changes in **shape**: forces can cause bodies to **stretch**, **compress**, or **deform**

Different forces



The effects of different forces on objects

Tension

- Tension is:

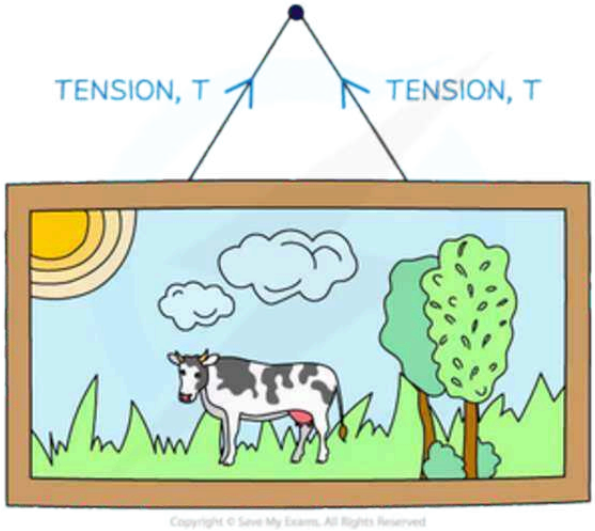
The force experienced by a cable, rope, or string when pulled, hung, rotated or supported

- This is normally labelled as *T* on free body diagrams

Tension force on a Picture Frame

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Your notes



Tension always acts away from the mass

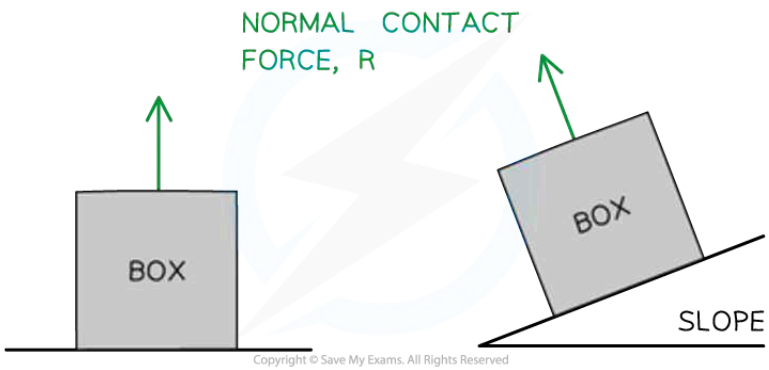
Normal Contact Force

- The normal contact force is:

> **The force arising when an object rests against another object acting at a 90° angle to the plane of contact**

- It is sometimes also referred to as the **reaction** force
- This is normally labelled as *N* or *R* on free body diagrams
- This force arises from Newton's Third Law

Normal Contact Force



Normal contact force is the force with which a surface pushes against an object. The normal contact force always acts perpendicularly to the surface

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Your notes

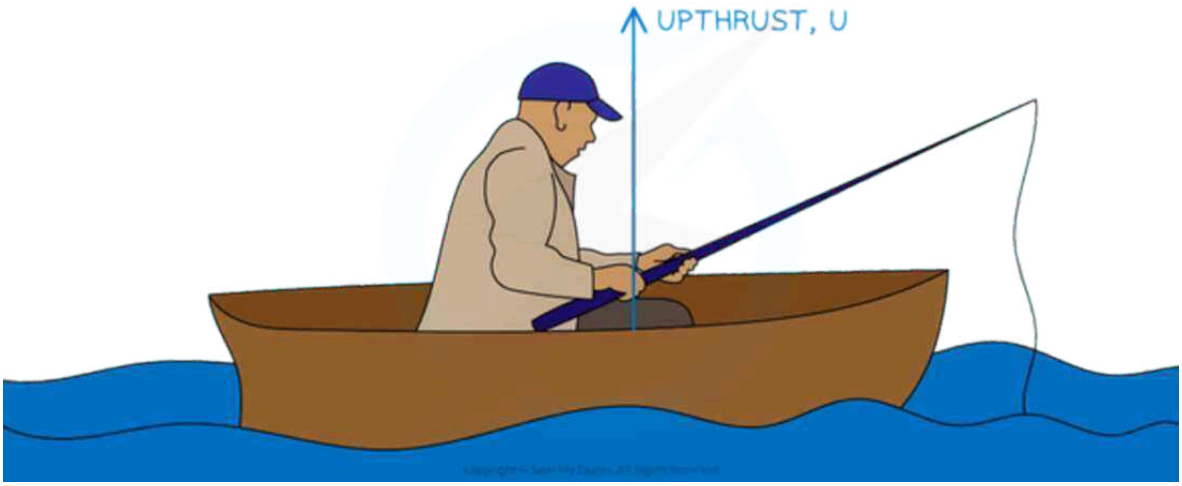
Upthrust

- Upthrust is:

The upward buoyancy force acting on an object when it is in a fluid

- Upthrust can occur in **liquids** and **gases**

Upthrust on a Boat



Upthrust always acts upwards

Friction

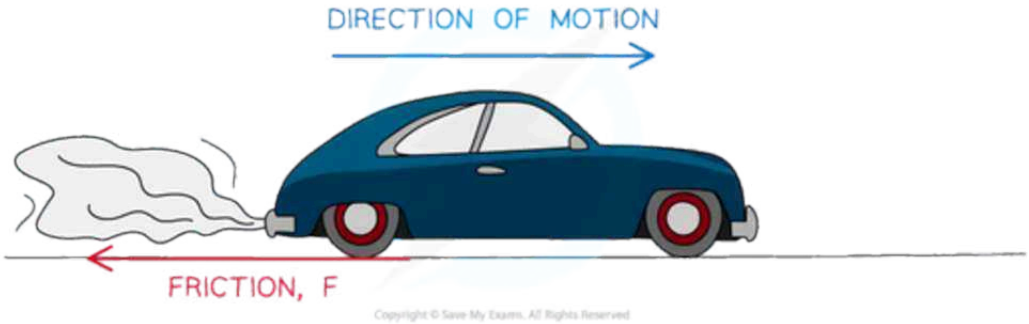
- Friction is:

The force that arises when two surfaces are in contact with each other

- Friction always **opposes** the motion
- This is normally labelled as *F* or *Fr* on free body diagrams

Force of Friction Acting on a Car

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Friction always acts at the point where the objects are in contact, and in the opposite direction to the direction of motion

Your notes

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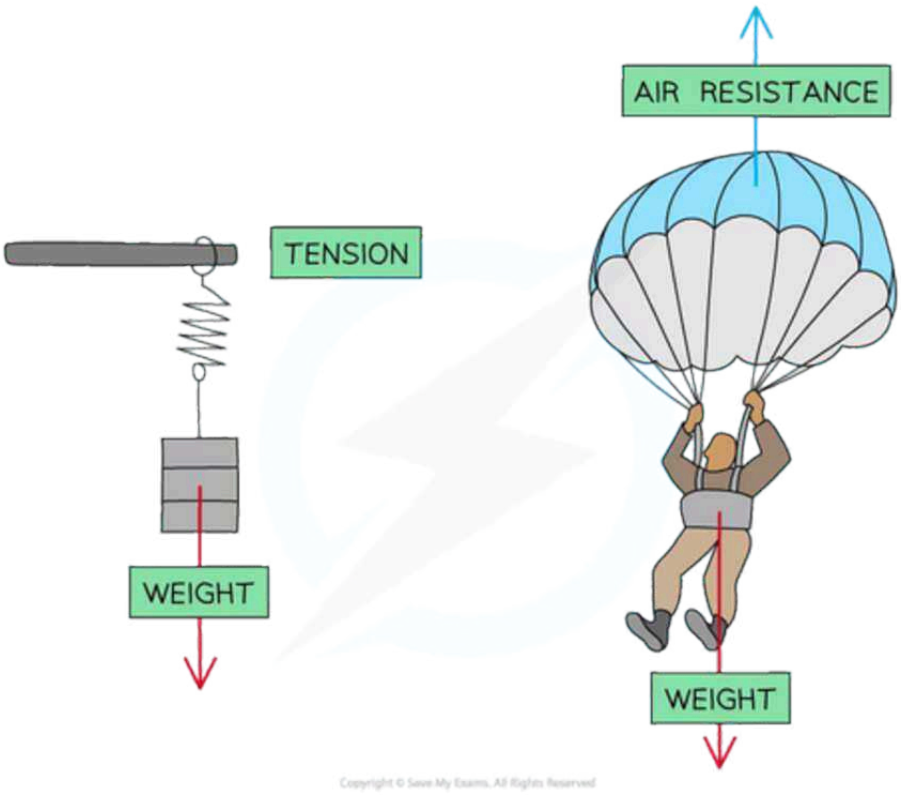
Identifying Forces Acting on an Object

Your notes

- Free body diagrams are useful for modelling the forces that are acting on an object
- Each force is represented as a **vector** arrow, where each arrow:
 - Is scaled to the **magnitude** of the force it represents
 - Points in the **direction** that the force acts
 - Is **labelled** with the name of the force it represents

- Free body diagrams can be used:
 - To identify which forces act in which plane
 - To resolve the net force in a particular direction

Force Diagrams of a Mass on a Spring, and a Parachuter



Free body diagrams can be used to show the various forces acting on objects

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Your notes

Worked example

Draw free-body diagrams for the following scenarios:

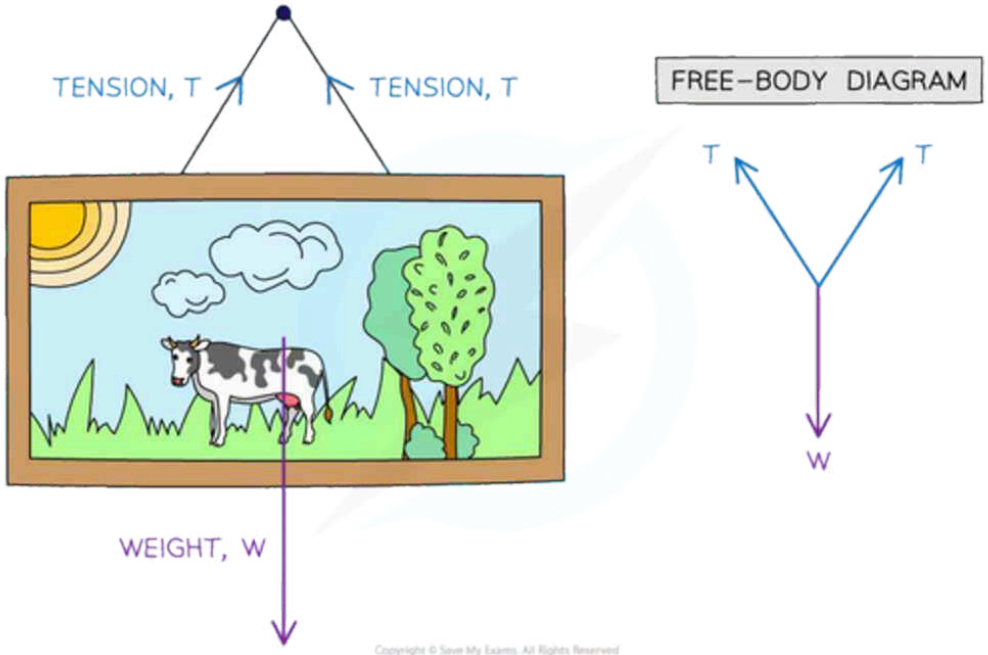
a) A picture frame hanging from a nail

b) A box sliding down a slope

c) A car accelerating along a road

Answer:

(a)

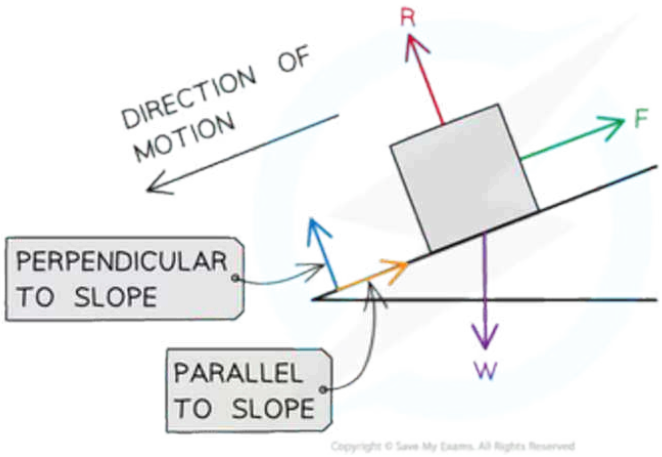


- The size of the arrows should be such that the 3 forces would make a closed triangle as they are **balanced**

(b)

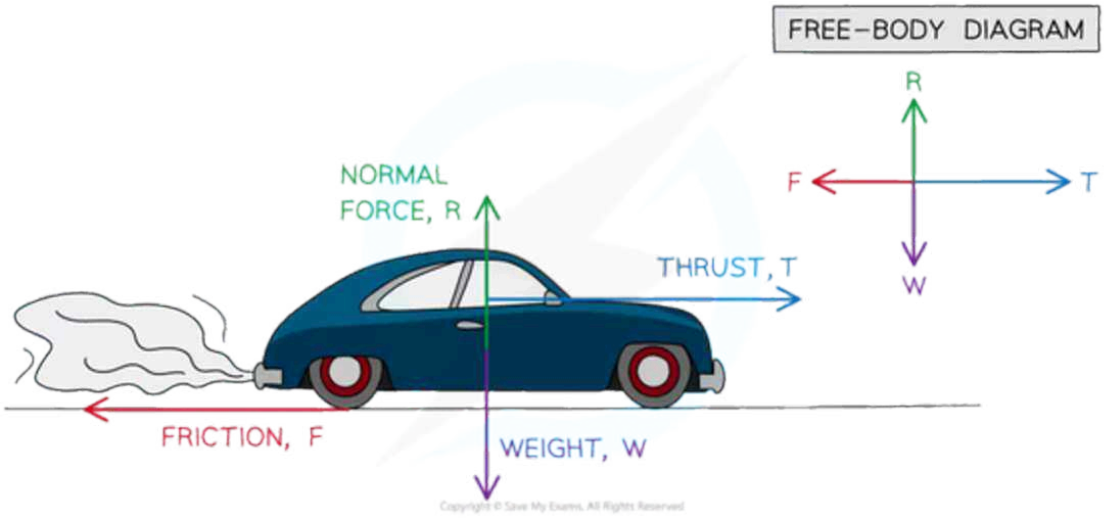
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Your notes



- There are three forces acting on the box
- The **normal contact force**, *R*, acts perpendicular to the slope
- **Friction**, *F*, acts parallel to the slope and in the opposite direction to the direction of motion
- **Weight**, *W*, acts down towards the Earth

(c)



- As the car is accelerating, the size of the thrust must be **larger** than the size of the friction force
- The upwards and downwards forces must be **equal**

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Worked example

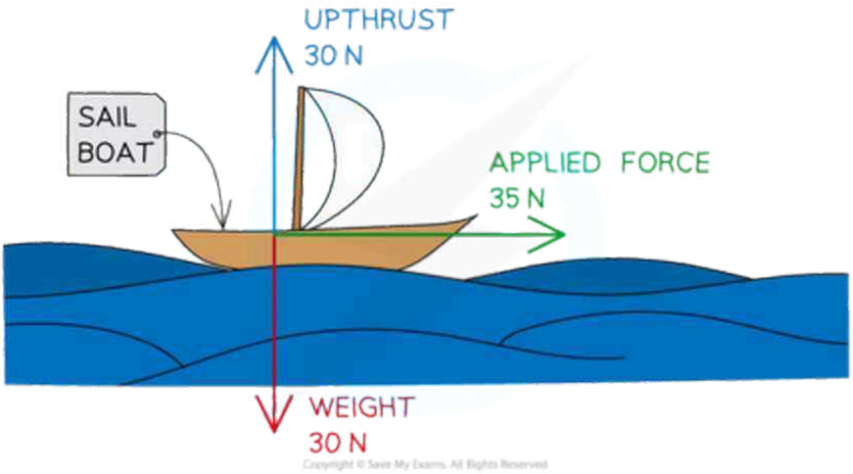
Draw a free-body diagram of an toy sail boat with weight 30N floating in water that is being pulled to the right by an applied force of 35N.

Answer:

Step 1: Identify all of the forces acting upon the object in the question, including any forces that may be implied

- **Weight**: 30N down
- **Upthrust** from the water (since the object is floating): 30N up
- **Applied force**: 35N to the right

Step 2: Draw in all of the force vectors (arrows), making sure the arrows start at the object and are directed away



- An approximation can be made as to the final resultant force due to all of the forces
 - Decide whether the resultant force is approximately up or down
 - Decide whether the resultant force is approximately left or right
 - For example: The resultant force is directed **up** and to the **right**

Your notes

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Resultant Forces on a Straight Line

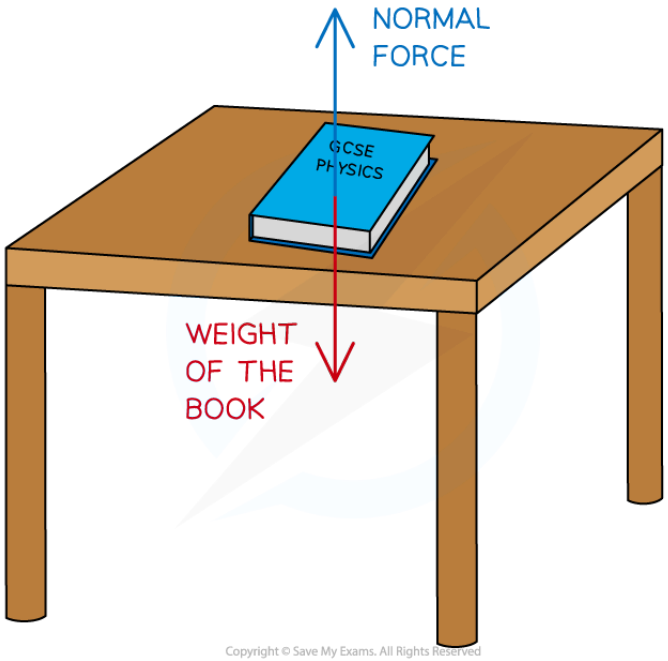
Your notes

- A **resultant force** is a single force that describes all of the forces operating on a body
- When many forces are applied to an object they can be combined (added) to produce one final force which describes the **combined action** of all of the forces
- This single resultant force determines:
 - The **direction** in which the object will move as a result of all of the forces
 - The **magnitude** of the final force experienced by the object

- The resultant force is sometimes called the **net force**
- Forces can combine to produce
 - **Balanced** forces
 - **Unbalanced** forces

- **Balanced** forces mean that the forces have combined in such a way that they cancel each other out and no resultant force acts on the body
 - For example, the **weight** of a book on a desk is balanced by the **normal** force of the desk
 - As a result, **no resultant force** is experienced by the book, the book and the table are **equal** and **balanced**

Balanced Forces Acting on a Book at Rest on a Table



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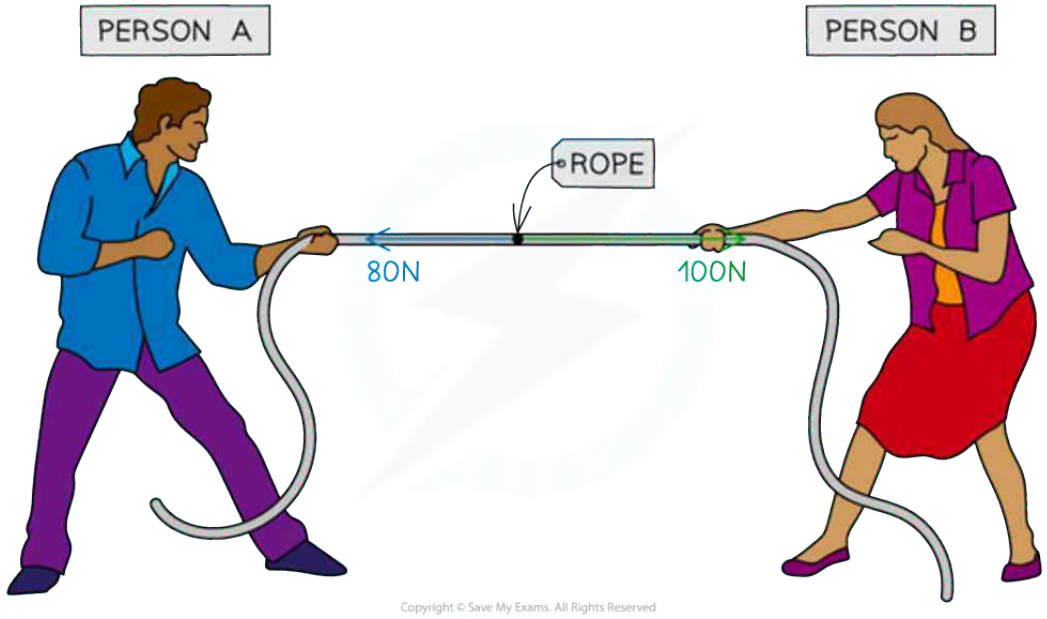
The upward acting normal contact force is equal to the force of weight, therefore the forces acting on the book ate balanced

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Your notes

- **Unbalanced** forces mean that the forces have combined in such a way that they do not cancel out completely and there is a **resultant force** on the object
 - For example, imagine two people playing a game of tug-of-war, working against each other on opposite sides of the rope
 - If person **A** pulls with 80 N to the left and person **B** pulls with 100 N to the right, these forces do not cancel each other out completely
 - Since person **B** pulled with more force than person **A** the forces will be unbalanced and the rope will experience a resultant force of 20 N to the right

Unbalanced Forces in a Game of Tug-of-War



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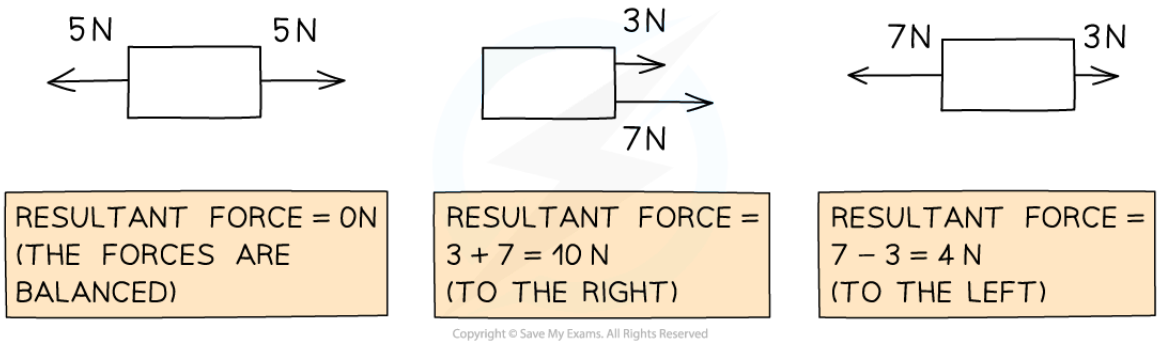
The force exerted on the rope by Person B is greater than the force exerted on the rope by Person A, therefore the forces acting on the rope are unbalanced

- Resultant forces can be calculated by adding or subtracting all of the forces acting on the object
 - Forces working in opposite directions are **subtracted** from each other
 - Forces working in the same direction are **added** together

- If the forces acting in opposite directions are equal in size, then there will be no resultant force – the forces are said to be **balanced**

Resultant Forces on Different Objects

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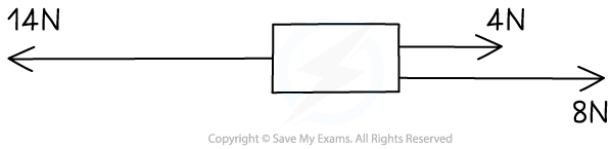
The resultant force is the net force acting on the object when all the individual forces have been added and the directional components accounted for

- Imagine the forces on the boxes as two people pushing on either side
 - In the first scenario, the two people are evenly matched - the box **doesn't move**
 - In the second scenario, the two people are pushing on the same side of the box, it moves to the right with their combined strength
 - In the third scenario, the two people are pushing against each other and are not evenly matched, so there is a **resultant force to the left**

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Worked example

Calculate the magnitude and direction of the resultant force in the diagram below.



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Answer:

Step 1: Add up all of the forces directed to the right

$$4\ N + 8\ N = 12\ N$$

Step 2: Subtract the forces on the right from the forces on the left

$$14\ N - 12\ N = 2\ N$$

Step 3: Evaluate the direction of the resultant force

- The force to the left is **greater** than the force to the right therefore the resultant force is directed to the left

Step 4: State the magnitude and direction of the resultant force

- The resultant force is 2 N to the left

Exam Tip

Remember to always provide units for your answer and to state whether the force is to the left, to the right, or maybe up or down

Always provide your final answer as a description of the **magnitude** and the **direction**, for example:

- Resultant Force = **4 N to the right**

Your notes

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Newton's First Law

Your notes

Newton's First Law of Motion

- Newton's **first law of motion** states:

> **Objects will remain at rest, or move with a constant velocity unless acted on by a resultant force**

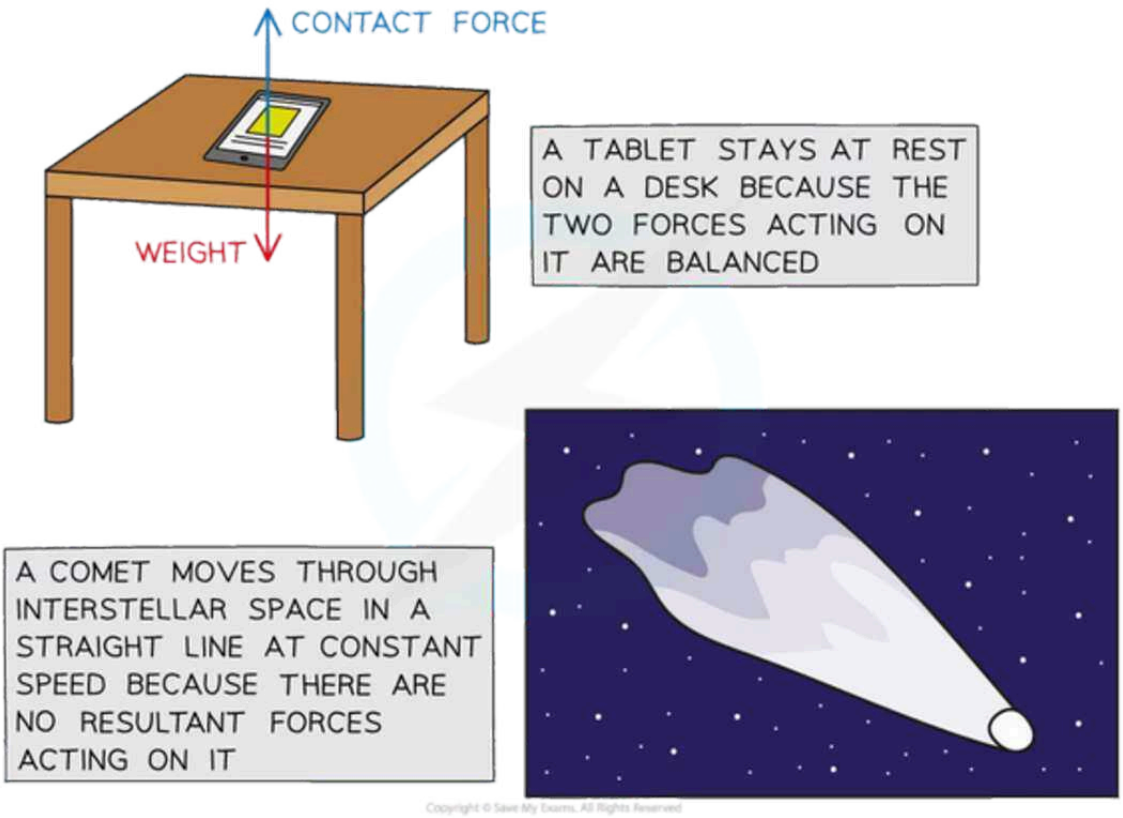
- This means if the resultant force acting on an object is zero:
 - The object will **remain stationary** if it was stationary before
 - The object will continue to move at the **same velocity** if it was moving
- When the resultant force is **not** zero
 - The **speed** of the object can change
 - The **direction** of the object can change

Applying Newton's First Law

- Newton's first law is used to explain why things move with a **constant** (or **uniform**) **velocity**
 - If the **forces** acting on an object are **balanced**, then the **resultant force** is **zero**
 - The velocity (i.e. speed and direction) **can only change** if a **resultant force** acts on the object

Examples of Objects with Uniform Velocity

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Constant velocity can only be achieved when the forces on an object are balanced - in other words, when the resultant force is zero

Your notes

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Worked example

Lima did some online research and found out that the Moon orbits the Earth at a constant speed of around 2000 mph. She says that this is not an example of Newton's first law of motion.

Is Lima correct? Explain your answer.

Answer:

Step 1: Recall Newton's first law of motion

- Newton's first law of motion states that **objects will remain at rest, or move with a constant velocity, unless acted on by a resultant force**

Step 2: Determine if the object in the question is at rest, or if it is moving with a constant velocity

- The Moon, in this case, is **not** at rest
- It is moving at a **constant speed**
- But it is **not** moving in a **constant direction** - it continually orbits the Earth
- Hence, it is not moving with a constant velocity, because velocity is a vector quantity

Step 3: State and explain whether Lima is correct

- Lima is **correct**
- The Moon moves with a **constant speed**, but always **changes direction**
- So it is **not** moving with a **constant velocity**, and is **not** an example of Newton's first law of motion



Your notes

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Worked example

There are no external forces acting on the car and it is moving at a constant velocity.

State the value of the frictional force, *F*.



Answer:

Step 1: Recall Newton's first law of motion

- Newton's first law of motion states that **objects will remain at rest, or move with a constant velocity unless acted on by a resultant force**

Step 2: Relate Newton's first law to the scenario

- Since the car is moving at a constant velocity, there is no resultant force
- This means the driving and frictional forces are balanced

Step 3: State the value of the frictional force

- Frictional force, *F* = driving force = **3 kN**

Your notes

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Newton's Second Law

Your notes

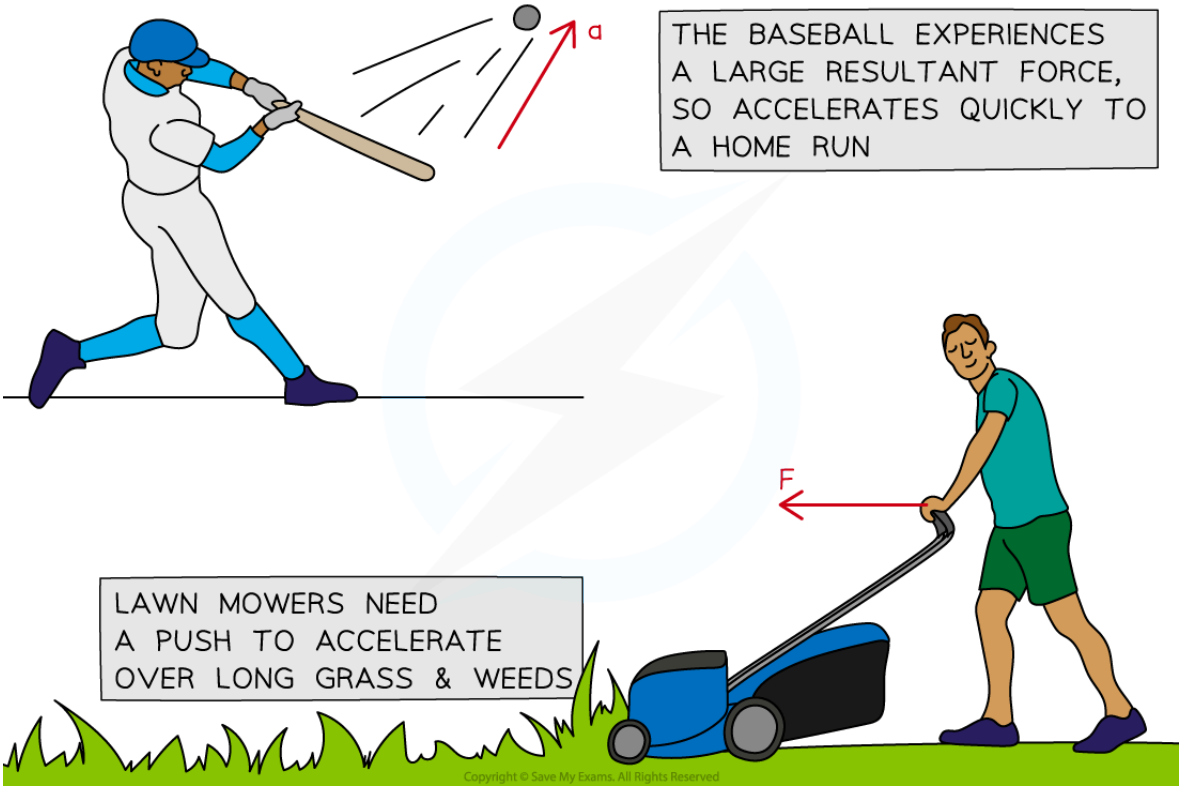
Newton's Second Law

- Newton's **second law of motion** states:

> **The acceleration of an object is proportional to the resultant force acting on it and inversely proportional to the object's mass**

- Newton's second law explains the following important principles:
 - An object will **accelerate** (change its velocity) in response to a **resultant force**
 - The **bigger** this resultant force, the **larger** the acceleration
 - For a given force, the **greater** the object's mass, the **smaller** the acceleration experienced

Examples of Newton's Second Law



Objects like baseballs and lawnmowers accelerate when a resultant force is applied on them. The size of the acceleration is proportional to the size of the resultant force

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Calculations Using Newton's Second Law

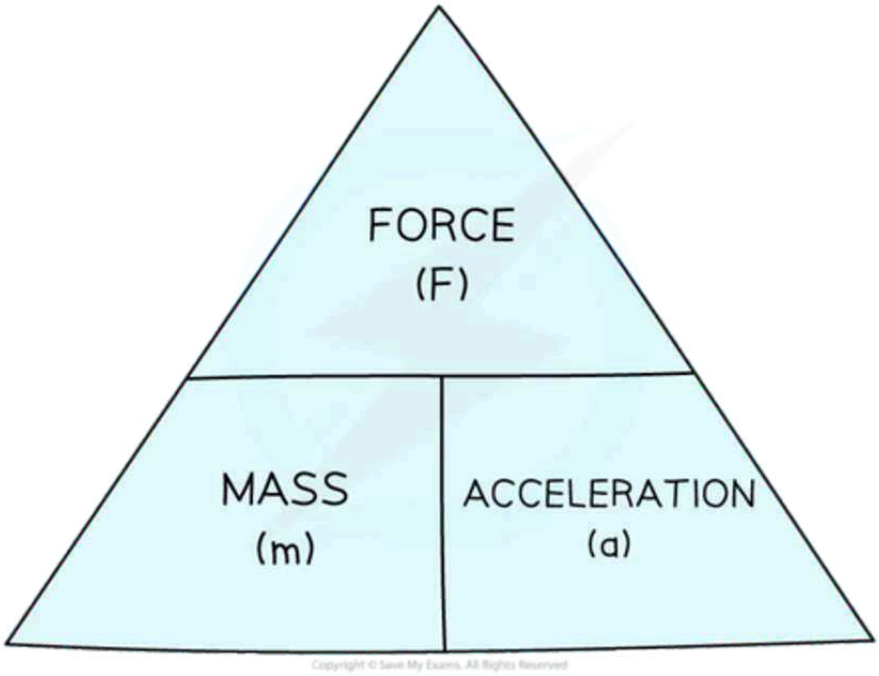
Your notes

- Newton's second law can be expressed as an equation:

$$F = ma$$

- Where:
 - F = resultant force on the object in Newtons (N)
 - m = mass of the object in kilograms (kg)
 - a = acceleration of the object in metres per second squared (m/s^2)
- The **force** and the **acceleration** act in the **same direction**
- This equation can be rearranged with the help of a formula triangle:

Equation Triangle for Newton's Second Law



Force, mass, acceleration formula triangle; you can use this if you need support with the rearrangement until you feel able to do it on your own

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Your notes

Worked example

A car salesman says that his best car has a mass of 900 kg and can accelerate from 0 to 27 m/s in 3 seconds.

Calculate:

a) The acceleration of the car in the first 3 seconds.

b) The force required to produce this acceleration.

Answer:

(a)

Step 1: List the known quantities

- Initial velocity = 0 m/s
- Final velocity = 27 m/s
- Time, t = 3 s

Step 2: Calculate the change in velocity

$$\text{change in velocity} = \Delta v = \text{final velocity} - \text{initial velocity}$$

$$\Delta v = 27 - 0 = 27 \text{ m/s}$$

Step 3: State the equation for acceleration

$$a = \frac{\Delta v}{t}$$

Step 4: Calculate the acceleration

$$a = \frac{27}{3} = 9 \text{ m/s}^2$$

(b)

Step 1: List the known quantities

- Mass of the car, m = 900 kg
- Acceleration, $a = 9 \text{ m/s}^2$

Step 2: Identify which law of motion to apply

- The question involves quantities of **force**, **mass** and **acceleration**, so Newton's second law is required:

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$F = ma$

Step 3: Calculate the force required to accelerate the car

$F = 900 \times 9 =$ **8100 N**

Your notes

Worked example

Three shopping trolleys, **A**, **B** and **C**, are being pushed using the same force. This force causes each trolley to accelerate.



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Which trolley will have the smallest acceleration? Explain your answer.

Answer:

Step 1: Identify which law of motion to apply

- The question involves quantities of **force** and **acceleration**, and the image shows trolleys of different **masses**, so **Newton's second law** is required:

$F = ma$

Step 2: Re-arrange the equation to make acceleration the subject

$\square = \frac{\square}{\square}$

Step 3: Explain the inverse proportionality between acceleration and mass

- Acceleration is **inversely proportional** to mass
- This means for the **same amount of force**, a **large mass** will experience a **small acceleration**
- Therefore, trolley **C** will have the smallest acceleration because it has the largest mass

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Newton's Third Law

Your notes

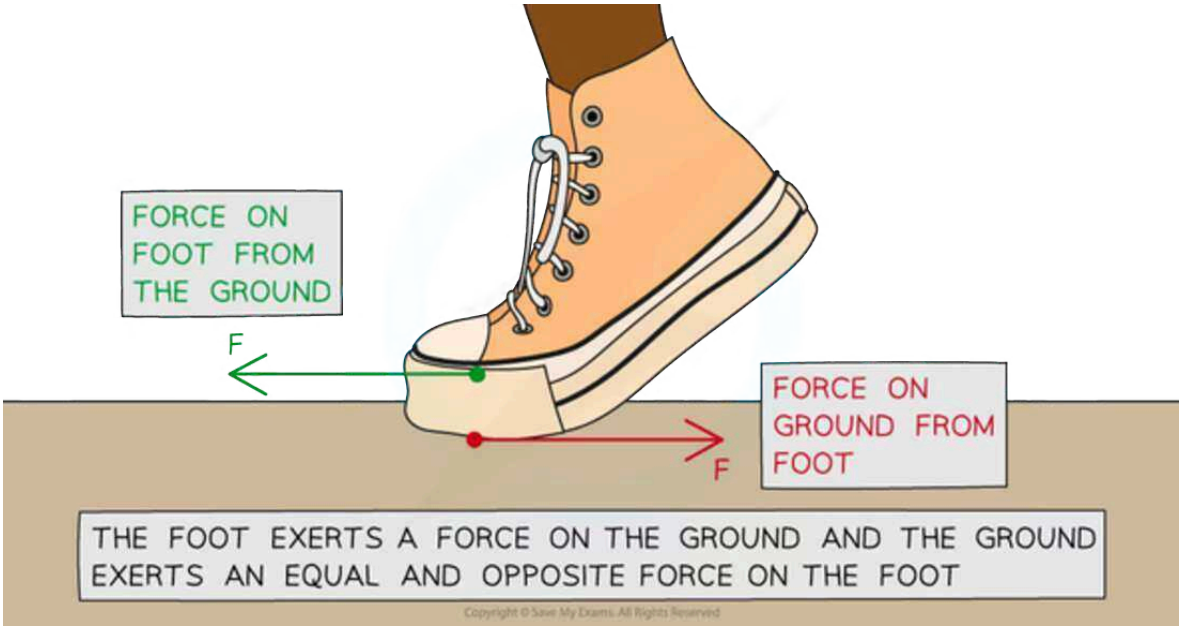
Newton's Third Law

- Newton's **third law of motion** states:

> **Whenever two bodies interact, the forces they exert on each other are equal and opposite**

- Newton's third law explains the following important principles about forces:
 - All forces arise in **pairs** - if object A exerts a force on object B, then object B exerts an **equal** and **opposite** force on object A
 - Force pairs are of the **same type** - for example, if object A exerts a **gravitational force** on object B, then object B exerts an equal and opposite **gravitational force** on object A
- Newton's third law explains the forces that enable someone to walk
- The image below shows an example of a pair of equal and opposite forces acting on two objects (the ground and a foot):

Example of Newton's Third Law



The foot pushes the ground backwards, and the ground pushes the foot forwards. Newton's third law explains the forces that enable people to walk

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- One force is from the foot that pushes the ground backwards
- The other is an **equal and opposite** force from the ground that pushes the foot forwards

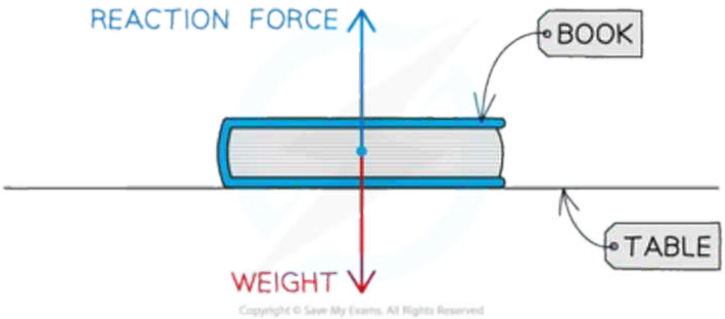

Your notes

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Your notes

Worked example

A physics textbook is at rest on a dining room table. Eugene draws a free body force diagram for the book and labels the forces acting on it.



Eugene says the diagram is an example of Newton's third law of motion. William disagrees with Eugene and says the diagram is an example of Newton's first law of motion.

By referring to the free-body force diagram, state and explain who is correct.

Answer:

Step 1: State Newton's first law of motion

- Objects will remain at rest, or move with a constant velocity unless acted on by a resultant force

Step 2: State Newton's third law of motion

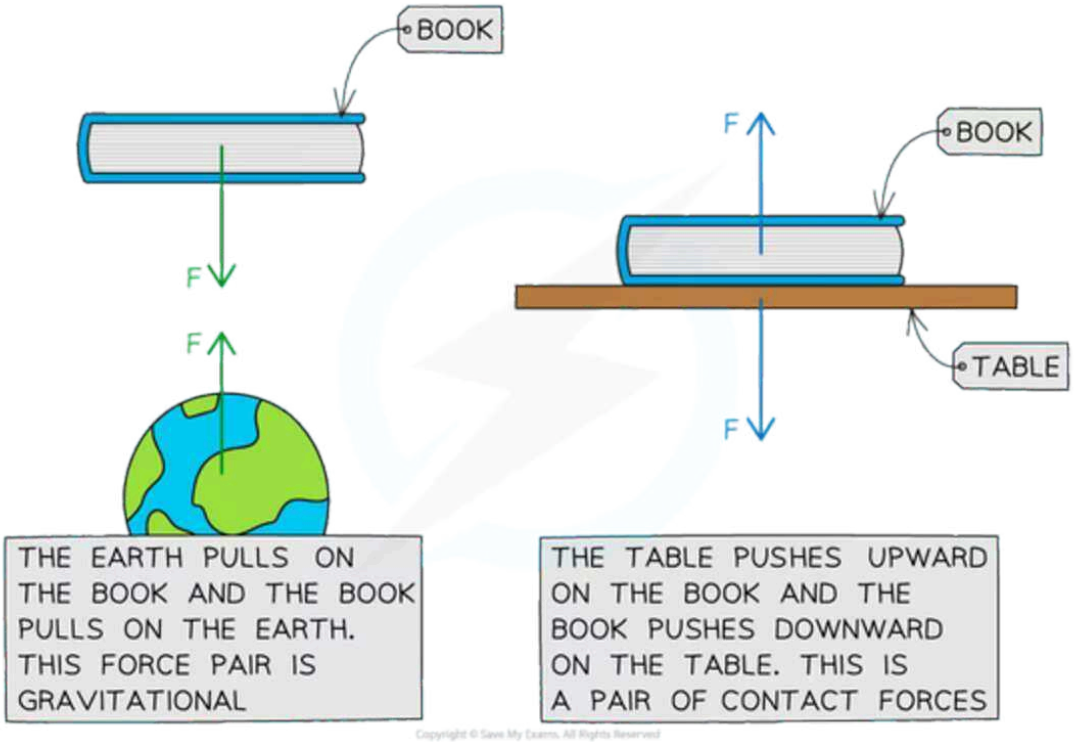
- Whenever two bodies interact, the forces they exert on each other are equal and opposite

Step 3: Check if the diagram satisfies the two conditions for identifying Newton's third law

- In each case, Newton's third law identifies pairs of equal and opposite forces, of the same type, acting on two different objects
- The diagram only involves **one object**
- Furthermore, the forces acting on the object are different types of force - one is a **contact force** (from the table) and the other is a **gravitational force** on the book (from the Earth) - its **weight**
- The image below shows how to apply Newton's third law correctly in this case, considering the pairs of forces acting:

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Your notes



Step 4: Conclude who is correct

- In this case, **William is correct**
- The free-body force diagram in the question is an example of **Newton's first law**
- The book is **at rest** because the two forces acting on it are **balanced** - i.e. there is no **resultant force**

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Exam Tip

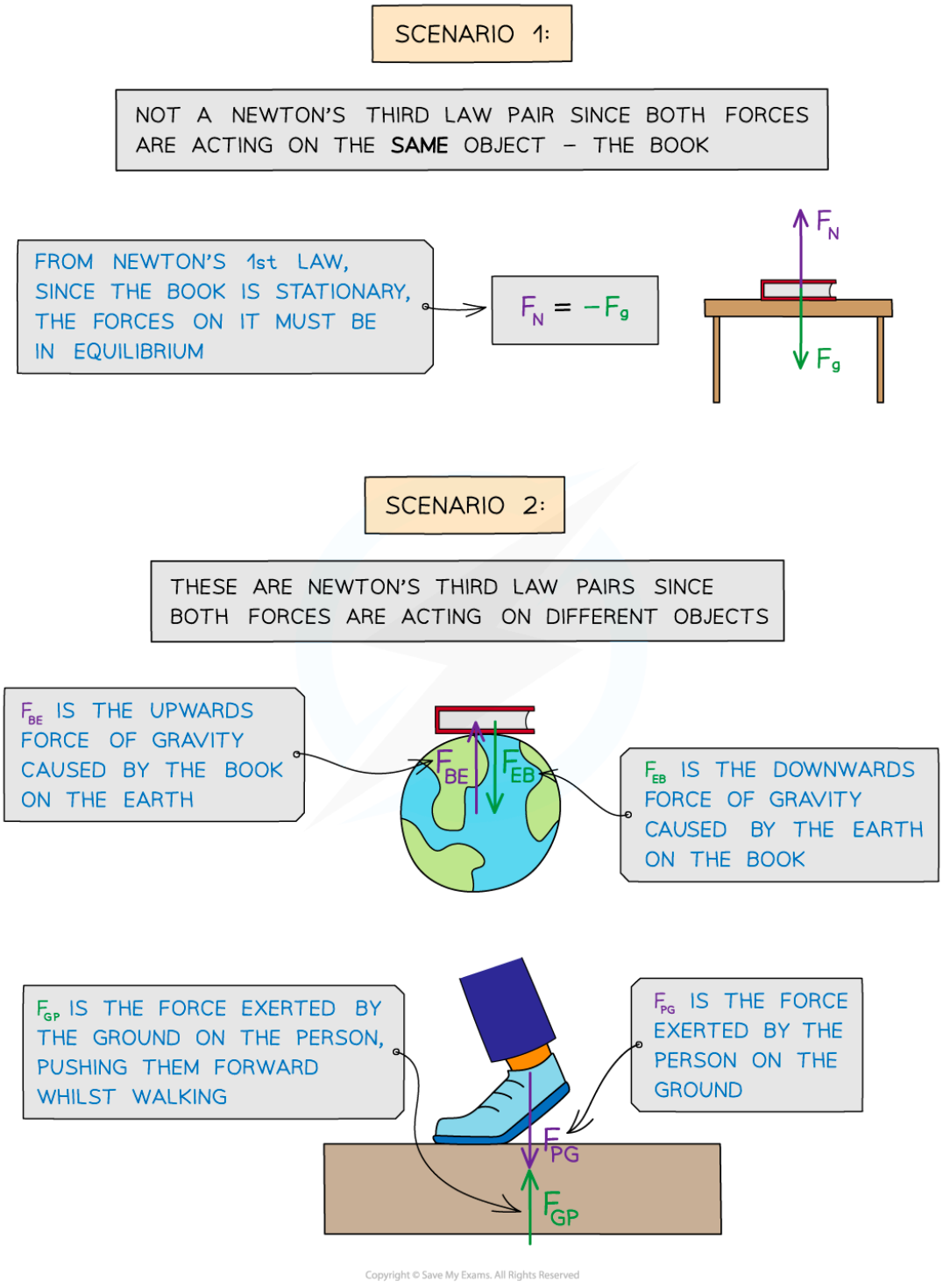
Remember that pairs of equal and opposite forces in Newton's third law act on **two different objects.** It's a really common mistake to confuse Newton's third law with Newton's first law, so applying this check will help you distinguish between them. Newton's first law involves forces acting on a **single** object. These differences are shown in Scenario 1 (Newton's first law) vs. Scenario 2 (Newton's third law)



Your notes

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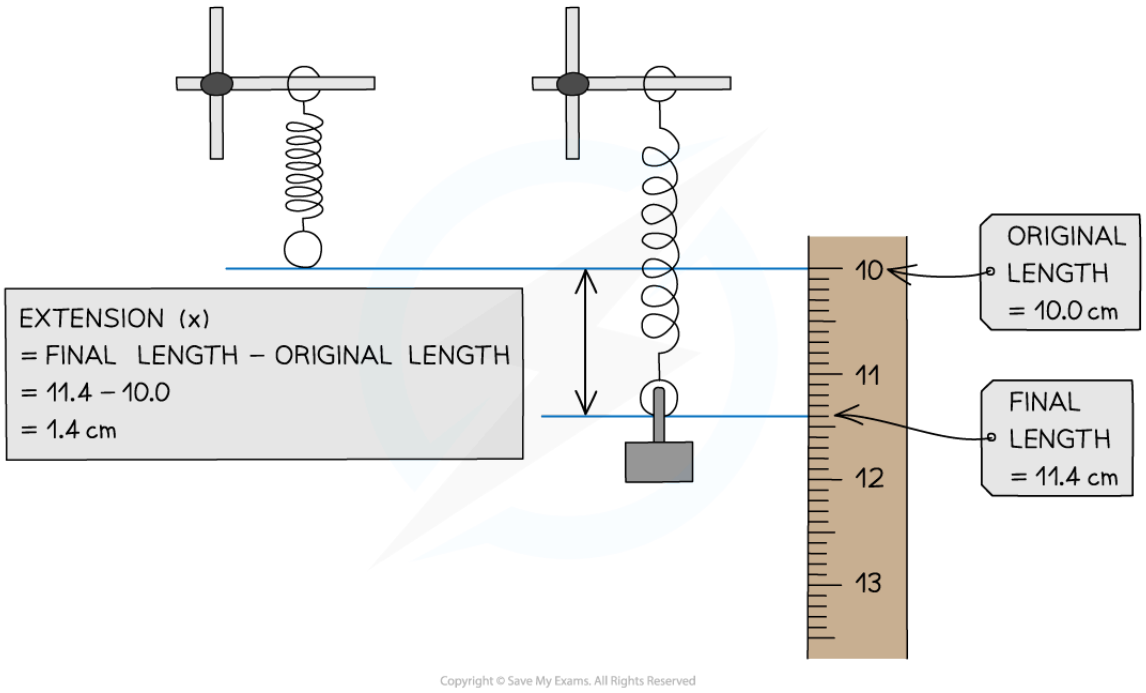
Investigating Force & Extension

Your notes

Investigating Springs

- When forces are applied to materials, the size and shape of the material can change
- The method below describes a typical procedure for carrying out an investigation into the properties of a material

Experimental Set-Up to Measure the Extension of a Spring



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To measure the extension of a spring, masses are hung from the spring and the extension of the spring is measured with a ruler

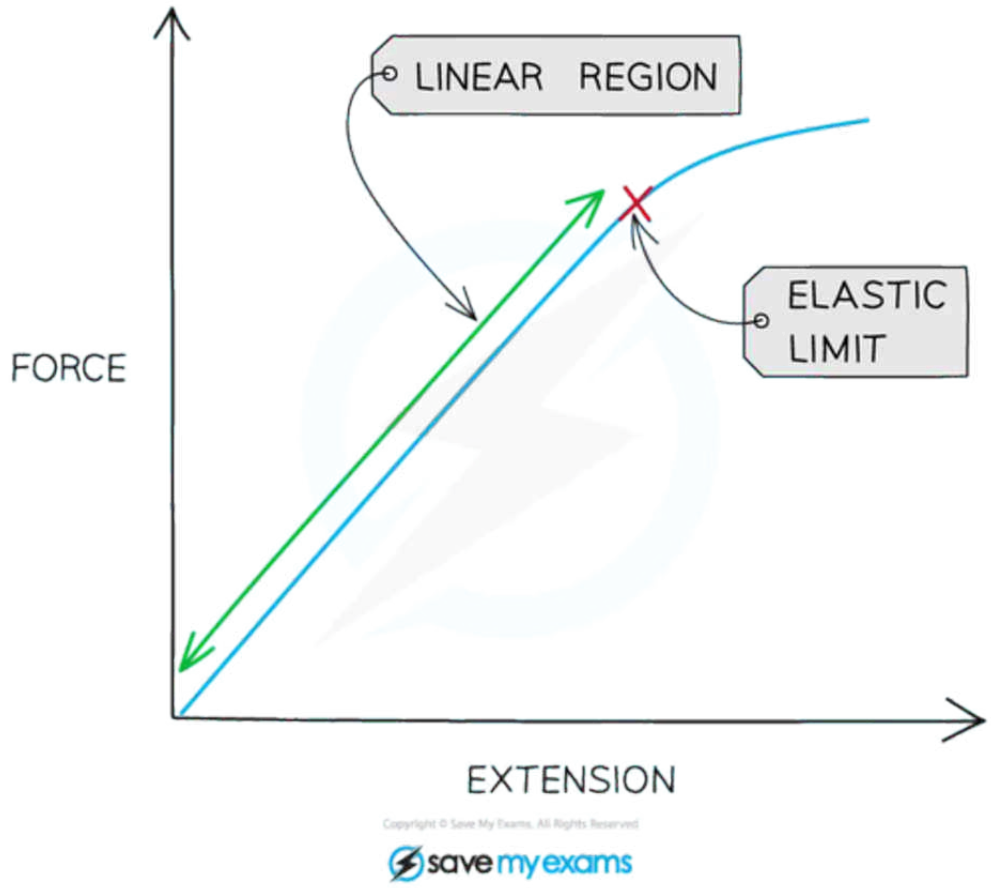
- Set up the apparatus as shown in the diagram
- A single mass (0.1 kg, 100g) is attached to the spring, with a pointer attached to the bottom, and the position of the spring is measured against the ruler
- The mass (in kg) and position (in cm) are recorded in a table
- A further mass is added and the new position measured
- The above process continues until a total of 7 masses have been added

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Your notes

- The masses are then removed and the entire process repeated again, until it has been carried out a total of three times, and averages can then be taken
- Once measurements have been taken:
 - The force on the spring can be found by multiplying the mass on the spring (in kg) by 9.81 N/kg (the gravitational field strength)
 - The extension of the spring can be found by subtracting the original position of the spring from each of the subsequent positions
- Finally, a graph of extension (on the y-axis) against force (on the x-axis) should be plotted

Force-Extension Graph



A graph of force against extension for a metal spring

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Hooke's Law


Your notes

Hooke's Law

- Hooke's law states that:

The extension of a spring is proportional to the applied force

$$\text{force} = \text{spring constant} \times \text{extension}$$

$$F = kx$$

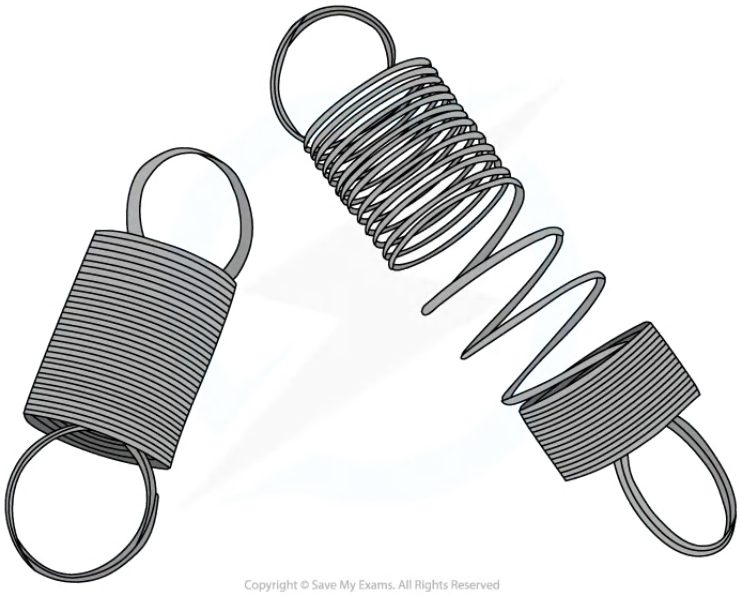
- Where:
 - F is the force applied
 - k is the spring constant
 - x is the extension of the spring

- The spring constant is the **force per unit extension**
 - The units are **N/m**
 - The spring constant is a measure of how stiff the spring is

- Many other materials (such as metal wires) also obey Hooke's law
- Hooke's law is associated with the initial linear (straight) part of a force-extension graph
- Objects that obey Hooke's law will return to their original length after being stretched
- If an object continues to be stretched it can be taken past the **limit of proportionality** (sometimes called the elastic limit). At this point the object will no longer obey Hooke's law and will not return to its original length

Spring Stretched Beyond its Elastic Limit

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The spring on the right has been stretched beyond the limit of proportionality

Exam Tip

A relationship is said to be **proportional** if the graph is a **straight line going through the origin.** If a graph is a straight line but **does not go through the origin** the relationship is said to be **linear.**

Your notes

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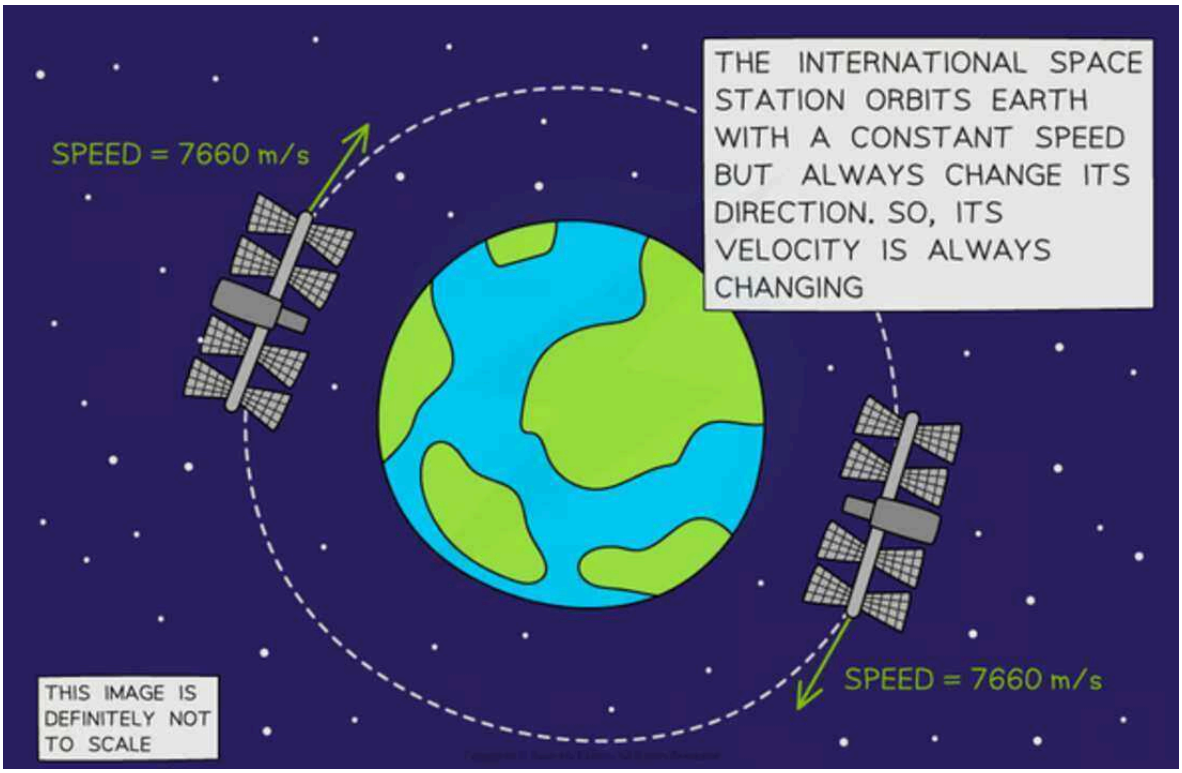
Circular Motion

Your notes

Circular Motion

- Velocity is a vector quantity, and the velocity of an object is its **speed** in a given **direction**
- When an object travels along a circular path, its velocity is always changing
 - The **speed** of the object moving in a circle might be constant - that is, it is travelling the same distance every second
 - However, the **direction** of travel is always changing as the object moves along the circular path
- This means that an object moving in circular motion travels at a **constant speed** but has a **changing velocity**
- The image below shows an example of a famous object that moves in a circular path with a constant speed but changing direction:

International Space Station Orbiting Earth



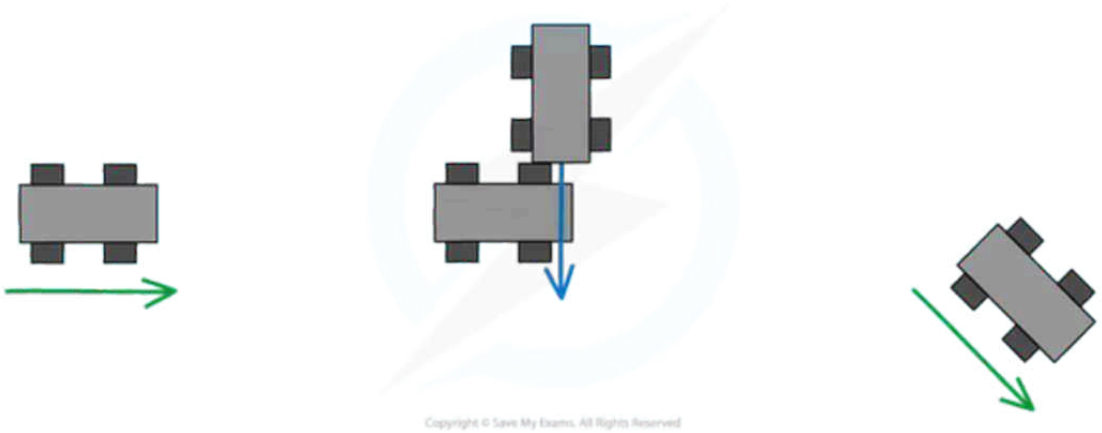
The International Space Station's velocity is always changing - it whizzes around the Earth at a constant speed of about 7660 m/s but is always changing direction

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Your notes

- **When a force acts at 90 degrees** to an object's direction of travel, the force will cause that object to change direction

An Impact Force Causing a Change in the Motion of a Car



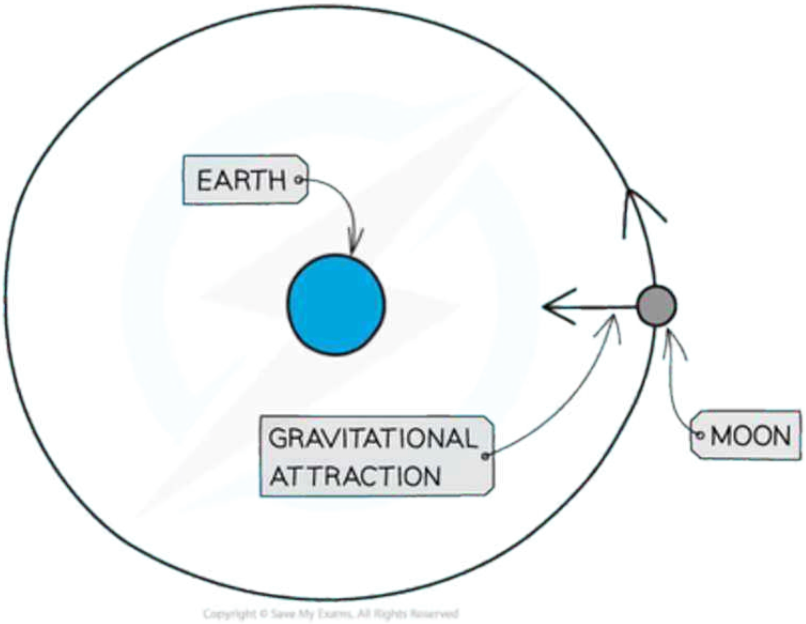
When the two cars collide, the first car changes its direction in the direction of the force

- If the force continues to act at 90 degrees to the motion, the object will keep changing its direction (whilst remaining at a constant speed) and travel in a circle
- This is what happens when a planet orbits a star (or satellite orbits a planet)

The Moon Orbiting the Earth

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Your notes



The Moon is pulled towards the Earth (at 90 degrees to its direction of travel). This causes it to travel in a circular path

- The force needed to make something follow a circular path depends on a number of factors:
 - **The mass of the object**
 - A greater mass requires a greater force when the speed and radius are constant
 - **The speed of the object**
 - A faster-moving object requires a greater force when the mass and radius are constant
 - **The radius of the circle**
 - A smaller radius requires a greater force to keep the speed and radius constant

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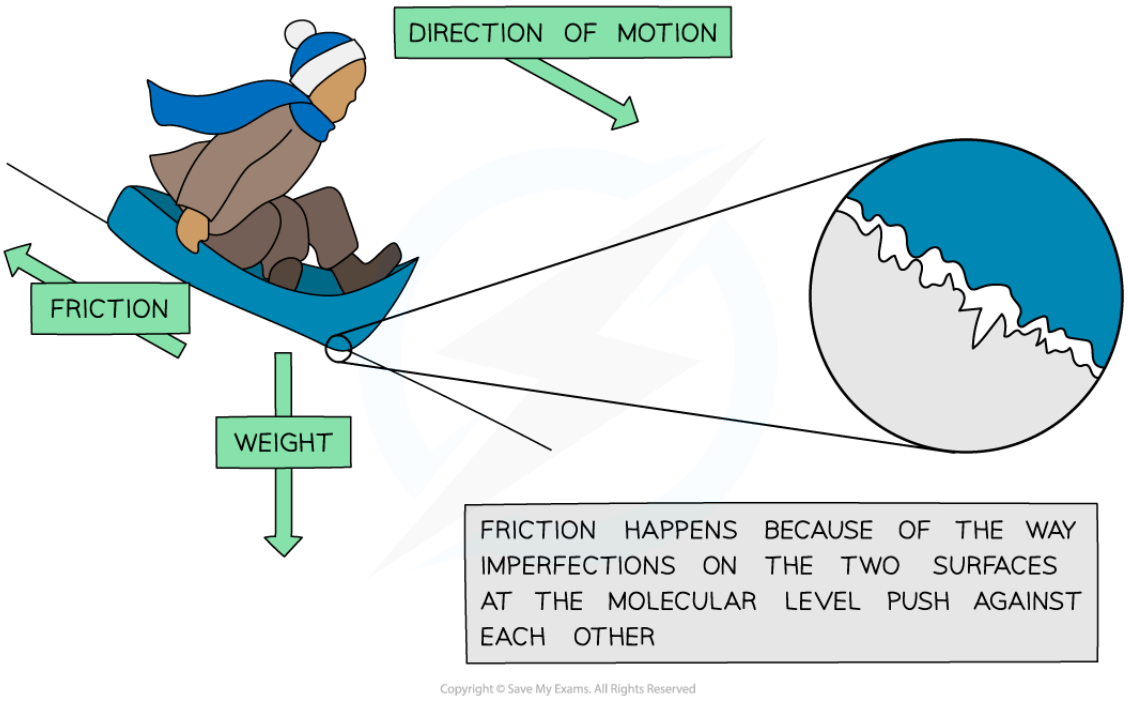
Friction

Your notes

Friction

- Friction is a force that works in **opposition** to the motion of an object
 - This slows down the motion of the object
- When friction is present, energy is transferred in the form of **heat**
 - This raises the **temperature** (thermal energy) of the object and its surroundings
 - The work done against the frictional forces causes this rise in the temperature
- **Friction in solids** is caused by **imperfections** in the surfaces of the objects moving over one another
 - Not only does this slow the object down but also causes an increase in **thermal energy**

Friction Acting on a Sledge



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The interface between the ground and the sledge is bumpy which is the source of the frictional force

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Motion of Objects & Drag

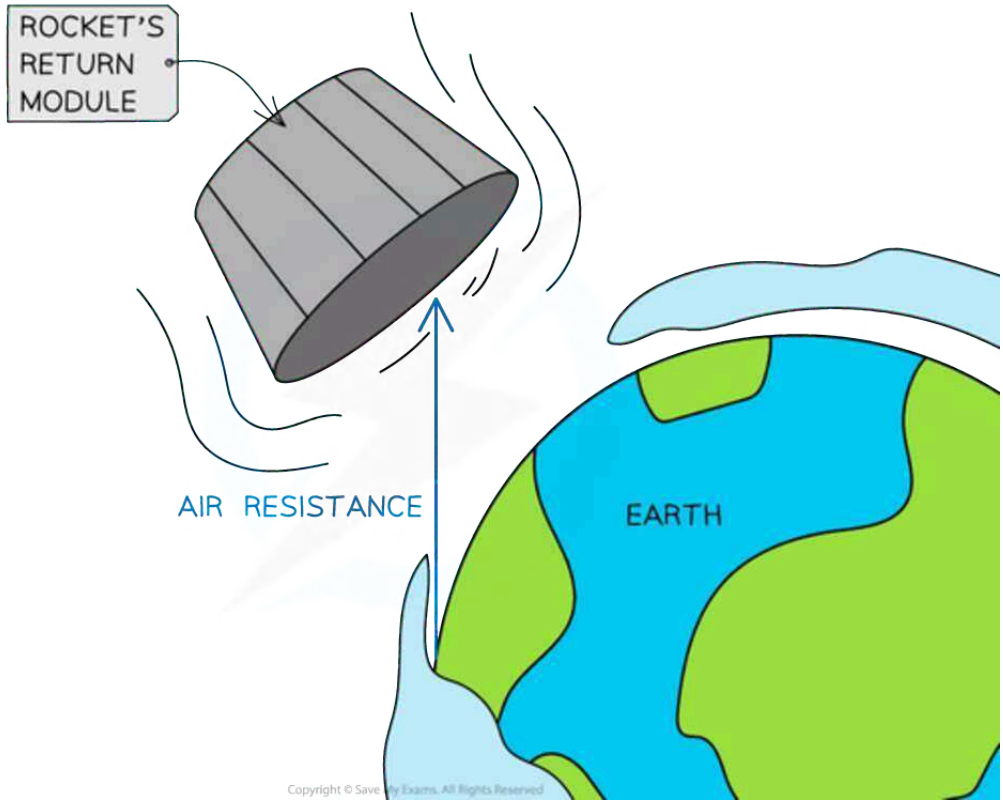
Friction in Fluids

Your notes

- **Gases** and **liquids** are known as **fluids**
 - Fluids are different to solids because the particles in fluids can move around
- Friction acts on objects moving through gases and liquids as the particles collide with the object
 - This type of friction is called **drag**

- Air resistance is a **type of friction** that slows the motion of an object
- Particles bump into the object as it moves through the air
 - As a result, the object heats up due to the work done against the frictional forces

Air Resistance Acting on Return Module



The return module of a rocket heats up due to the work done by air resistance as it travels a distance through the atmosphere

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Stopping Distances


Your notes

Stopping Distances

- The **stopping distance** of a car is defined as:

 The total distance travelled during the time it takes for a car to stop in response to some emergency

- It can be written as an equation involving two distances:

 Stopping distance = Thinking distance + Braking distance

- Where:
 - **Thinking distance** = the distance travelled in the time it takes the driver to react (reaction time) in metres (m)
 - **Braking distance** = the distance travelled under the braking force in metres (m)
 - **Stopping distance** = the sum of the thinking distance and braking distance, in metres (m)
- For a given braking force, the **greater the speed** of the vehicle, the **greater the stopping distance**

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Your notes

Worked example

At a speed of 20 m/s, a particular vehicle had a stopping distance of 40 metres. The car travelled 14 metres whilst the driver was reacting to the incident in front of him. What was the braking distance?

A 54 m

B 34 m

C 26 m

D 6 m

Answer: C

Step 1: Identify the different variables

- Stopping distance = 40 m
- Thinking distance = 14 m

Step 2: Rearrange the formula for stopping distance

Stopping distance = Thinking distance + Braking distance

Braking distance = Stopping distance – Thinking distance

Step 3: Calculate and identify the correct braking distance

- Braking distance = 40 – 14 = 26 metres
- Therefore, the answer is **C**

Factors affecting Stopping Distance

- There are various factors which can affect a vehicle's stopping distance. These are:
 - Vehicle **speed** - the greater the speed, the greater the vehicle's braking distance will be (because the brakes will need to do more work to bring the vehicle to a stop)
 - Vehicle **mass** - a heavy vehicle, such as a lorry, takes longer to stop
 - Road **conditions** - wet or icy roads make it harder to decelerate
 - Driver **reaction time** - a driver's thinking distance depends on their reaction time. Being tired, or intoxicated (i.e. alcohol, or drugs) can increase reaction time

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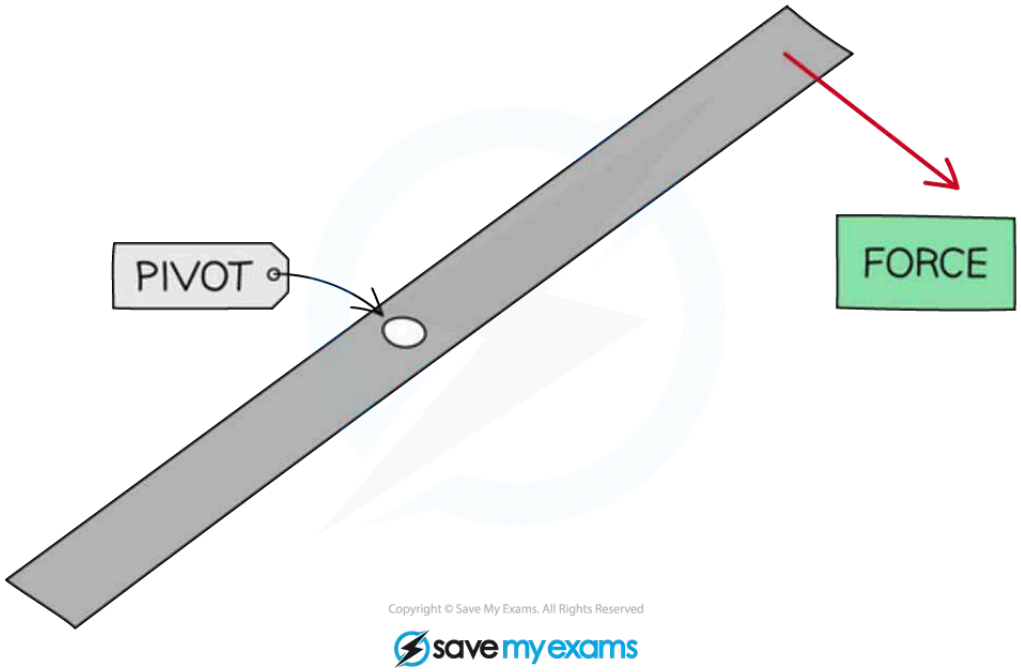
Moments

Your notes

Moments

- As well as causing objects to speed up, slow down, change direction and deform, forces can also cause objects to **rotate**
- An example of a rotation caused by a force is on one side of a pivot (a fixed point that the object can rotate around)
 - This rotation can be **clockwise** or **anticlockwise**

Pivot Point on a Metal Bar



The force will cause the object to rotate clockwise about the pivot

- A **moment** is defined as:

 The turning effect of a force about a pivot

- The size of a moment is defined by the equation:

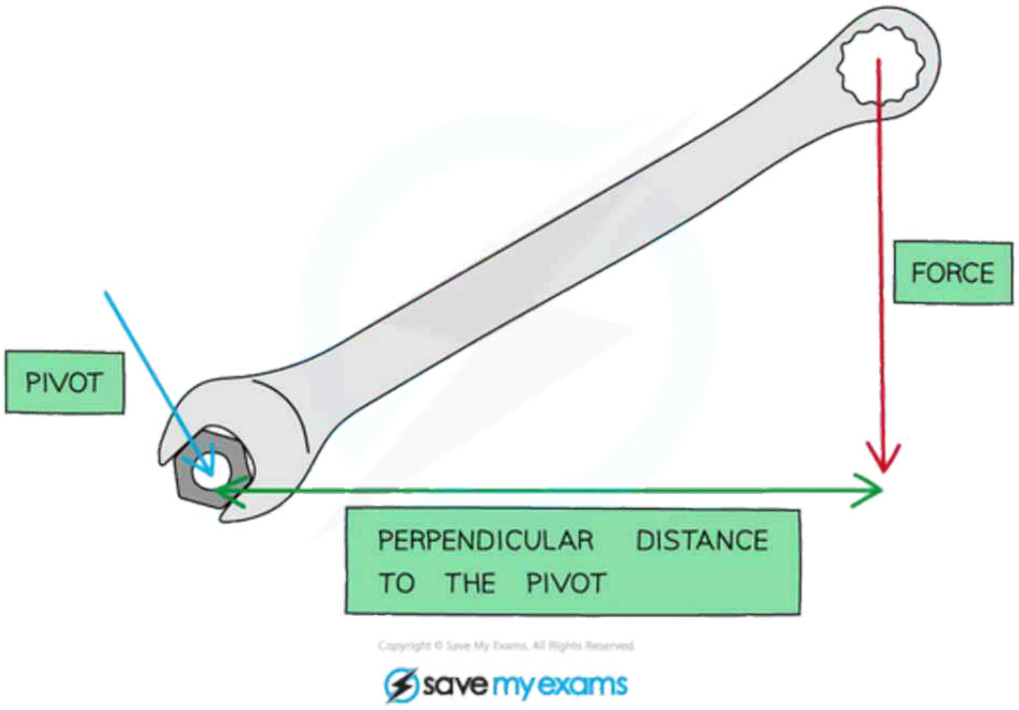
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$$M = F \times d$$

- Where:
 - M = moment in newton metres (Nm)
 - F = force in newtons (N)
 - d = perpendicular distance of the force to the pivot in metres (m)

Your notes

Moment of a Spanner



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The moment depends on the force and perpendicular distance to the pivot

- This is why, for example, the door handle is placed on the opposite side to the hinge
 - This means for a given force, the perpendicular distance from the pivot (the hinge) is larger
 - This creates a larger **moment** (turning effect) to make it easier to open the door
- Opening a door with a handle close to the **pivot** would be much harder, and would require a lot more **force**
- Some other examples involving moments include:
 - Using a crowbar to prize open something
 - Turning a tap on or off

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- A wheelbarrow
- Scissors


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Equilibrium

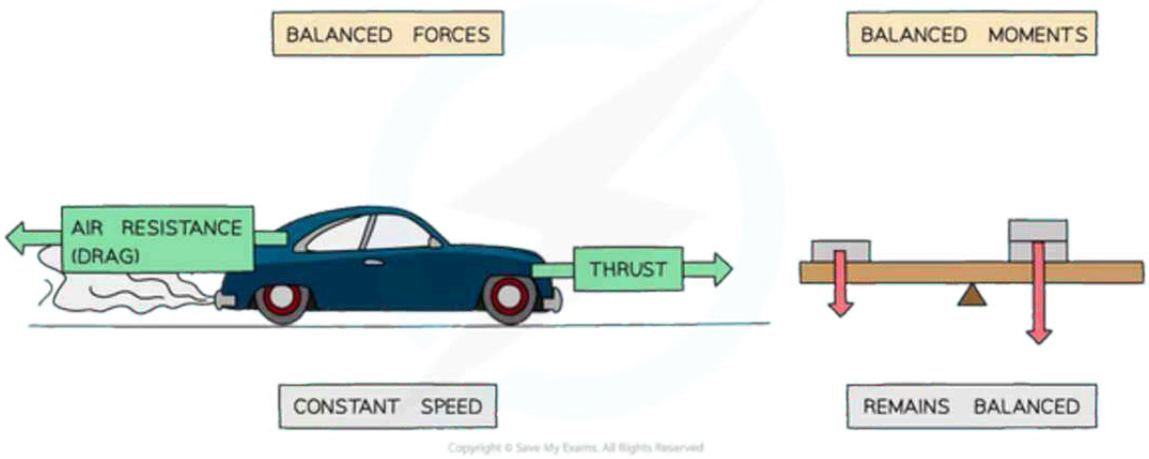
Your notes

The Principle of Moments

- The term **equilibrium** means that an object keeps doing what it's doing, without any change
- Therefore:
 - If the object is moving it will continue to move (in a straight line)
 - If it is stationary it will remain stationary
 - The object will also not start or stop turning

- The above conditions require two things:
 - **The forces on the object must be balanced**
 - There must be no **resultant force**
 - **The sum of clockwise moments on the object must equal the sum of anticlockwise moments**
 - there must be no **resultant moment**

A Moving Car and a Balanced Beam in Equilibrium



When the forces and moments on an object are balanced, the object will remain in equilibrium

- If the above two conditions are met, then **the object will be in equilibrium**

The Principle of Moments

- The principle of moments states that:

> **If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot**

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- Remember that the moment = **force × distance from a pivot**
- The forces should be **perpendicular** to the distance from the pivot
 - For example, on a horizontal beam, the forces which will cause a moment are those directed upwards or downwards

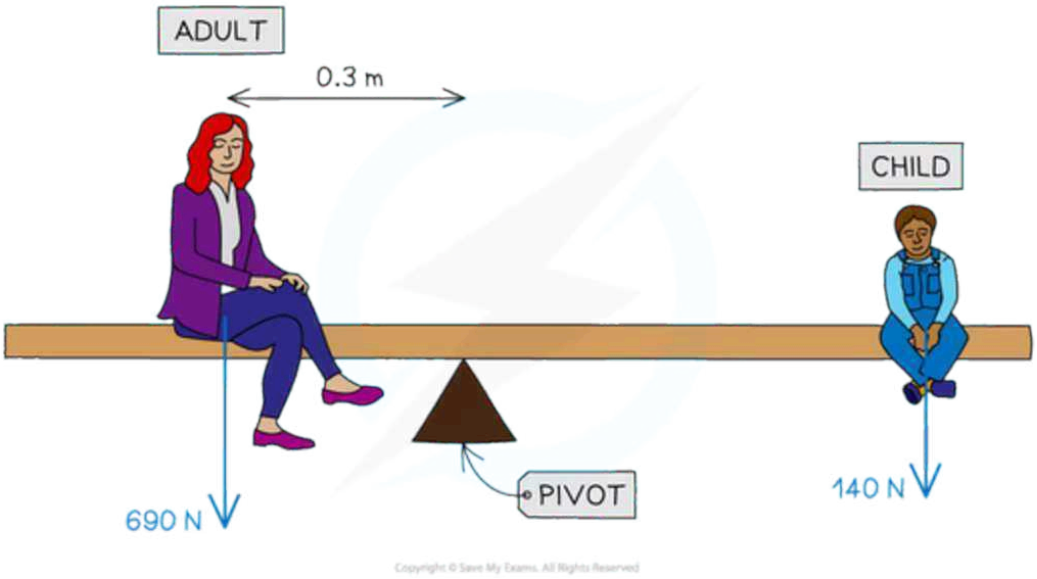

Your notes

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Your notes

Worked example

A parent and child are at opposite ends of a playground see-saw. The parent weighs 690 N and the child weighs 140 N. The adult sits 0.3 m from the pivot.



Calculate the distance the child must sit from the pivot for the see-saw to be balanced.

Answer:

Step 1: List the know quantities

- Clockwise force (child), $F_{child} = 140$ N
- Anticlockwise force (adult), $F_{adult} = 690$ N
- Distance of adult from the pivot, $d_{adult} = 0.3$ m

Step 2: Write down the relevant equation

- Moments are calculated using:

$$\text{Moment} = \text{force} \times \text{distance from pivot}$$

- For the see-saw to balance, the principle of moments states that

$$\text{Total clockwise moments} = \text{Total anticlockwise moments}$$

Step 3: Calculate the total clockwise moments

- The clockwise moment is from the child

$$\text{Moment}_{child} = F_{child} \times d_{child} = 140 \times d_{child}$$

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Step 4: Calculate the total anticlockwise moments

- The anticlockwise moment is from the adult

$$\text{Moment}_{adult} = F_{adult} \times d_{adult} = 690 \times 0.3 = 207 \text{ Nm}$$

Step 5: Substitute into the principle of moments equation

$$140 \times d_{child} = 207$$

Step 6: Rearrange for the distance of the child from the pivot

$$d_{child} = 207 \div 140 = 1.48 \text{ m}$$

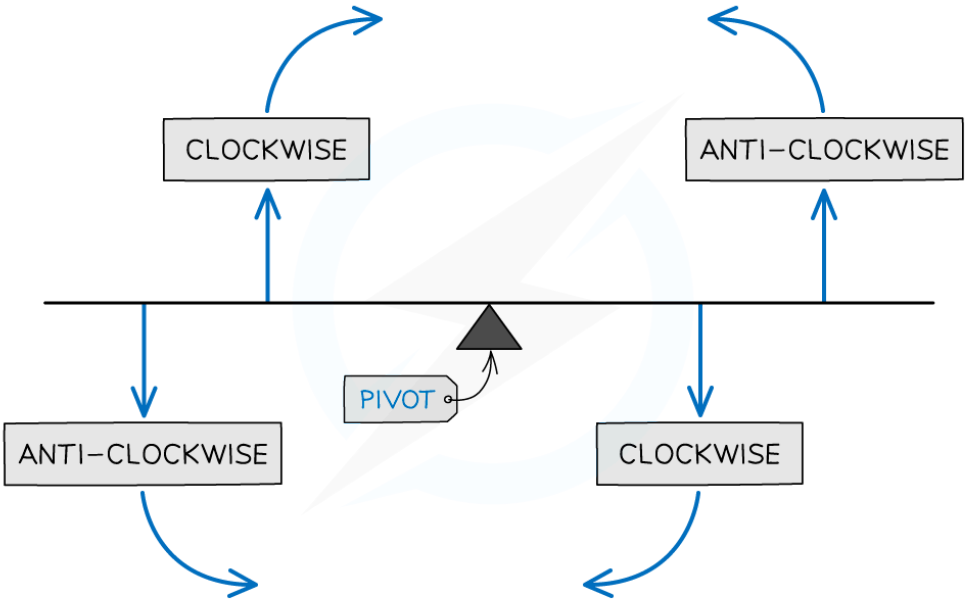


Your notes

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Exam Tip

Make sure that all the distances are in the same units and you're considering the correct forces as **clockwise** or **anticlockwise**, as seen in the diagram below

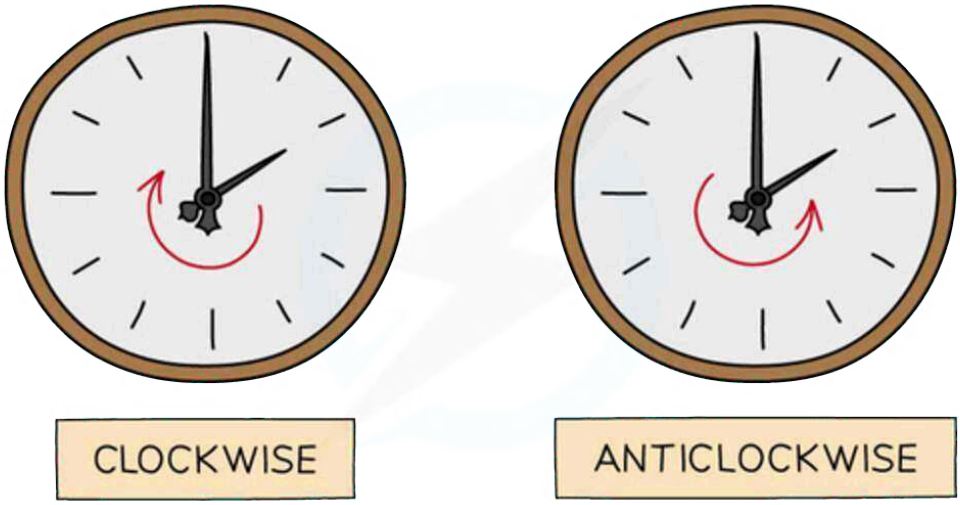


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Clockwise is defined as the direction the hands of a clock move (and anticlockwise as the opposite)

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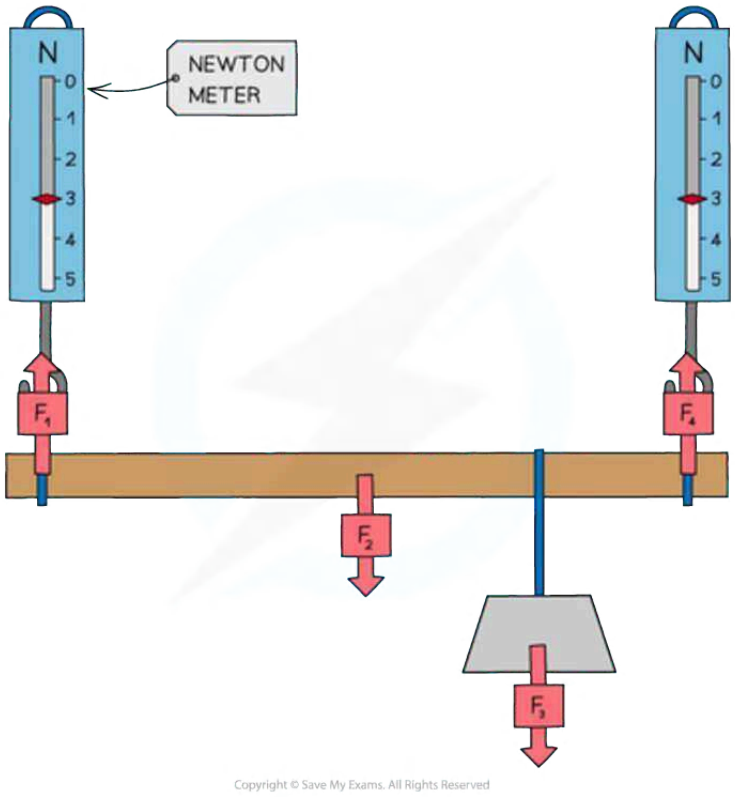
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Demonstrating Equilibrium

Your notes

- A simple experiment to demonstrate that there is no net moment on an object in equilibrium involves taking an object, such as a beam, and replacing the supports with newton (force) meters:

Forces on a Beam



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Several forces act on a supported beam, including the mass of the beam and the mass of an object suspended from it

- The beam in the above diagram is in equilibrium
- The various forces acting on the beam can be found either by taking readings from the newton meters or by measuring the masses (and hence calculating the weights) of the beam and the mass suspended from the beam
- The distance of each force from the end of the ruler can then be measured, allowing the moment of each force about the end of the ruler to be calculated
- It can then be shown that the sum of clockwise moments (due to forces F_2 and F_3) equal the sum of anticlockwise moments (due to forces F_1 and F_4)

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Your notes

More detail on setting up this experiment

- Use a meter ruler for the beam
- Suspend it via two Newton meters, one on each side, that each hang from a clamp stand
- F_1 is the reading given on the left side Newton meter and F_4 is the reading given on the right
- Create a loop of string, tie a tight knot and slide the ruler through it
- F_3 will be the weight of a mass hook with 10 N weights suspended from this string
- F_2 is the weight of the beam

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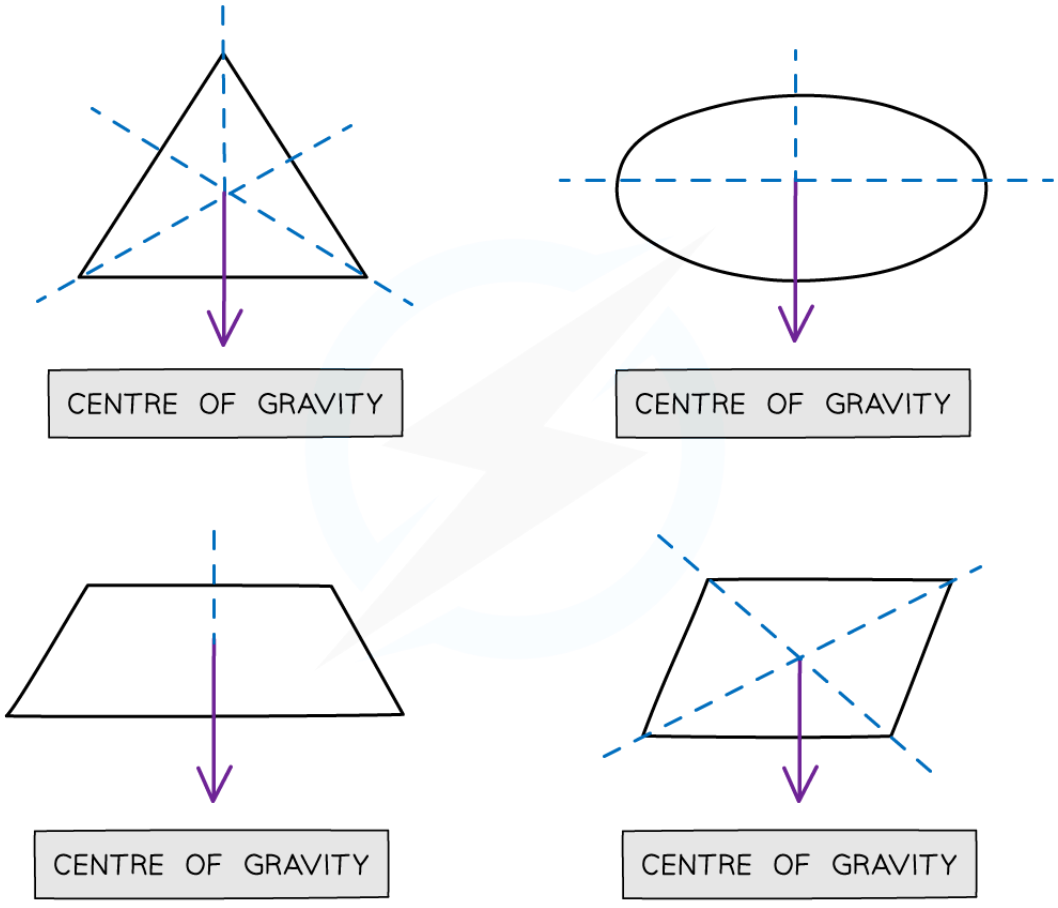
Centre of Gravity

Your notes

Centre of Gravity

- The centre of gravity of an object is **the point at which the weight of the object may be considered to act**
- For example, for a person standing upright, their centre of gravity is roughly in the middle of the body behind the navel, and for a sphere, it is at the centre
- For symmetrical objects with uniform density, the centre of gravity is located at the **point of symmetry**

Centre of Gravity of Differently Shaped Objects



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The centre of gravity of a shape can be found by symmetry

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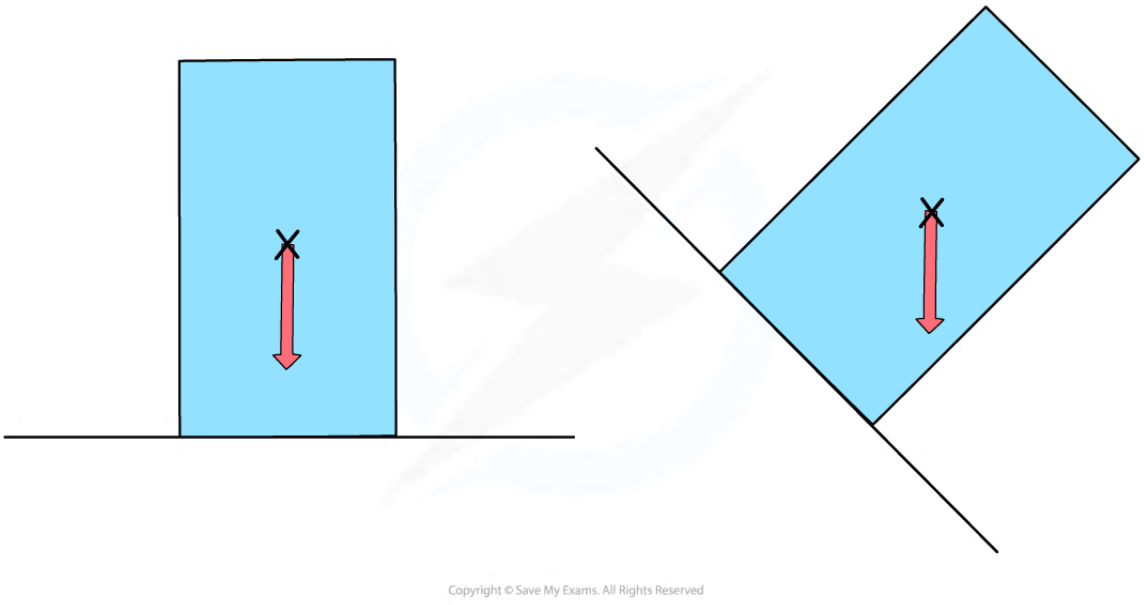
Stability

Stability

Your notes

- The position of the centre of gravity of an object affects its stability
- An object is stable when its centre of gravity lies above its base

Stability of Objects



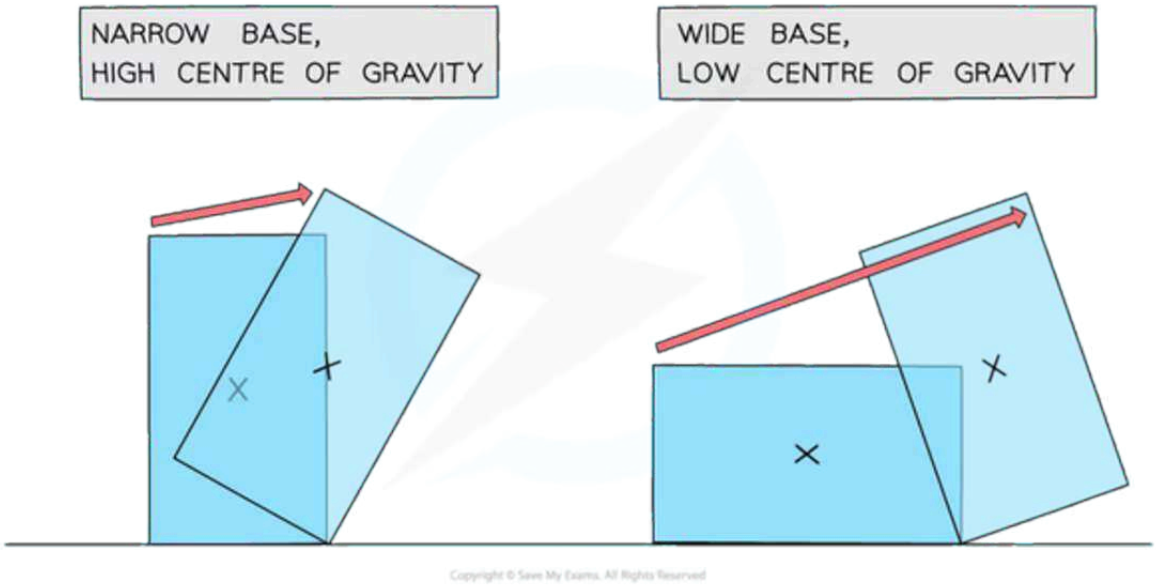
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The object on the right will topple, as its centre of gravity is no longer over its base

- The **wider** base an object has, the **lower** its centre of gravity and it is more **stable**
- The **narrower** base an object has, the **higher** its centre of gravity and the object is more likely to topple over if pushed

Stability of Objects with Different Sized Bases

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The most stable objects have wide bases and low centres of gravity

Your notes

Exam Tip

Since the centre of gravity is a hypothetical point, it can lie inside or outside of a body. The centre of gravity will constantly shift depending on the shape of a body. For example, a human body's centre of gravity is lower when learning forward than upright

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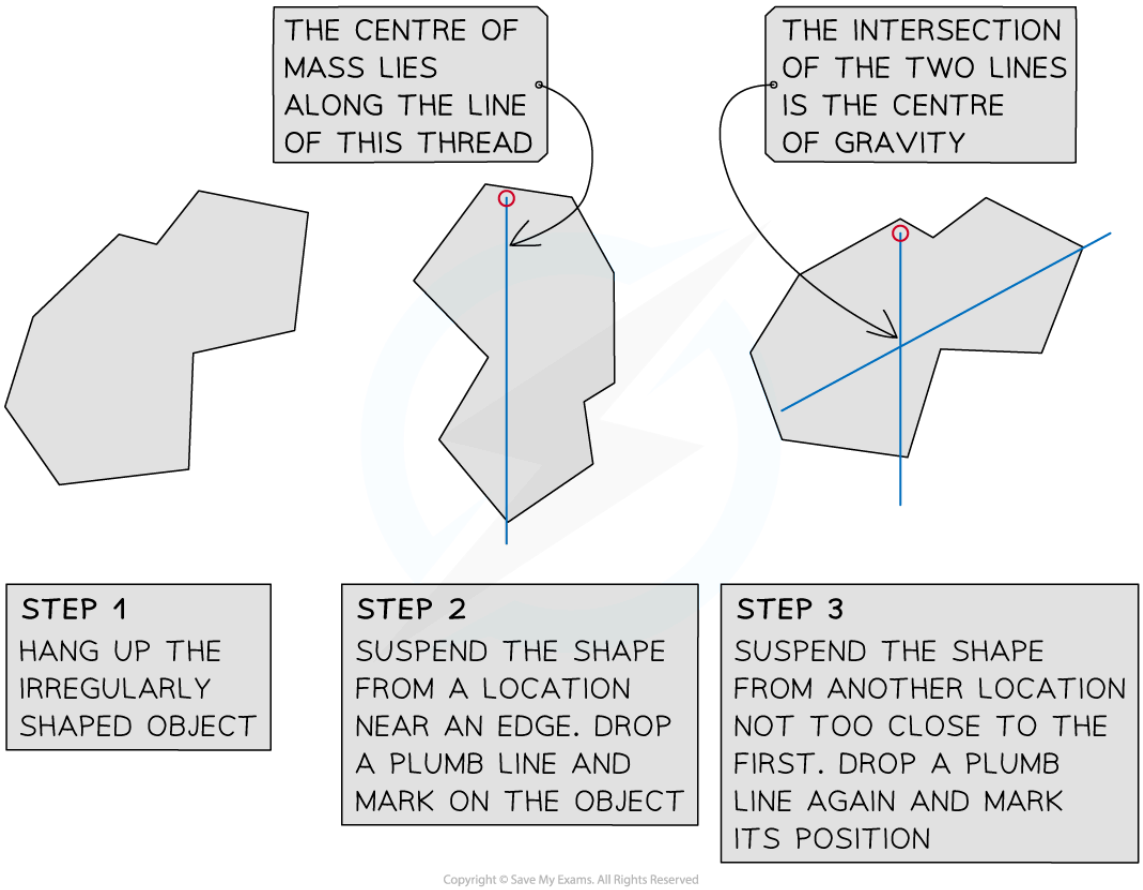
Investigating Centre of Gravity

Your notes

Investigating the Centre of Gravity

- **When an object is suspended from a point, the object will always settle so that its centre of gravity comes to rest below the pivoting point**
- This can be used to find the centre of gravity of an irregular shape:

Method for Finding the Centre of Gravity for Irregular Shapes



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Diagram showing an experiment to find the centre of gravity of an irregular shape

- The irregular shape (a plane laminar) is suspended from a pivot and allowed to settle

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- A plumb line (lead weight) is then held next to the pivot and a pencil is used to draw a vertical line from the pivot (the centre of gravity must be somewhere on this line)
- The process is then repeated, suspending the shape from two different points
- The centre of gravity is located at the point where all three lines cross


Your notes

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Cambridge O Level Physics

Your notes

1.6 Momentum

Contents

- Momentum & Impulse
- Impulse

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Momentum & Impulse

Your notes

Momentum

- An object with mass that is in motion has **momentum** which is defined by the equation:

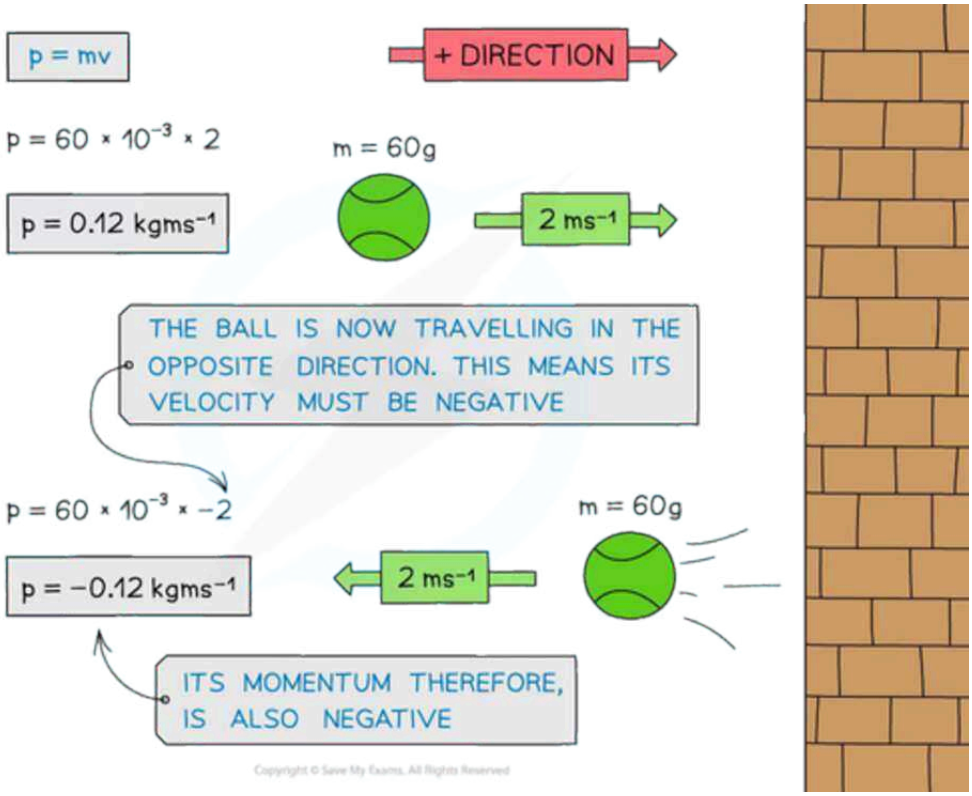
momentum = mass × velocity

$$p = mv$$

- Where:
 - p = momentum in kilogram metre per second (kg m/s)
 - m = mass in kilograms (kg)
 - v = velocity in metres per second (m/s)
- This means that an object at rest (i.e $v = 0$) has **no** momentum
- Momentum keeps an object moving in the same direction, making it difficult to change the direction of an object with a large momentum
- Since velocity is a vector this means that the momentum of an object also depends on its **direction** of travel
- This means that momentum can be either **positive** or **negative**
 - If an object travelling to the right has positive momentum, an object travelling in the opposite direction (to the left) will have negative momentum

Momentum of a Tennis Ball

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The tennis ball's momentum is negative when it moves in the opposite direction to which it initially was travelling in

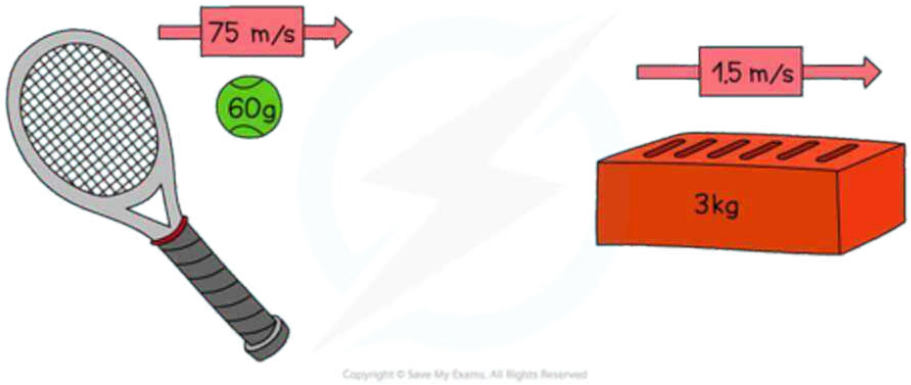
- Therefore, the momentum of an object will change if:
 - The object **accelerates** (speeds up) or **decelerates** (slows down)
 - Changes **direction**
 - Its **mass** changes

Your notes

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Worked example

Which object has the most momentum?



Answer:

- Momentum of tennis ball

$$p = mv$$

$$p = 0.06 \times 75$$

$$p = 4.5 \text{ kg m/s}$$

- Momentum of brick

$$p = mv$$

$$p = 3 \times 1.5$$

$$p = 4.5 \text{ kg m/s}$$

- Both the tennis ball and the brick have the same momentum
- Even though the brick is much heavier than the ball, the ball is travelling much faster than the brick
- This means that on impact, they would both exert a similar force (depending on the time it takes for each to come to rest)

Your notes

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Exam Tip

You can remember momentum as mass in motion. The units of momentum are **kg m/s** which is the product of the units of mass (kg) and velocity (m/s).

Which direction is taken as positive is completely up to you in the exam. In general, the right and upwards are taken as positive, and down or to the left as negative.



Your notes

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Conservation of Momentum

Your notes

- The principle of conservation of momentum states that:

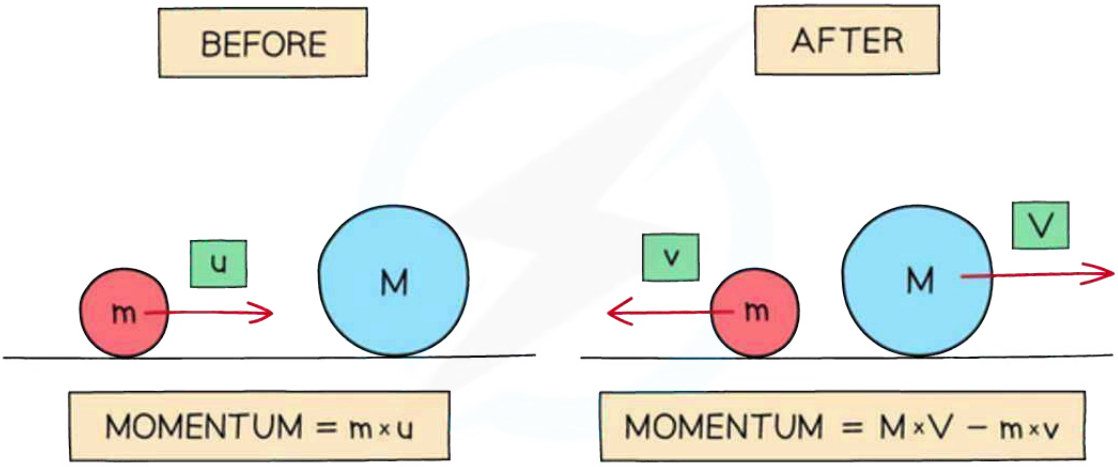
> **In a closed system, the total momentum before an event is equal to the total momentum after the event**

- A closed system means the energy within the system is constant and there is an absence of external forces (e.g. friction)
- In other words:

> **The total momentum before a collision = The total momentum after a collision**

- A system is a certain number of objects under consideration
 - This can be just one object or multiple objects
- Since momentum is a **vector** quantity, a system of objects moving in opposite directions (e.g. towards each other) at the same speed will have an overall momentum of 0 since they will **cancel out**
 - Momentum is **always conserved** over time
- The diagram below shows two masses *m* with velocity *u* and *M* at rest (ie. zero velocity)

Momentum of Masses Before and After a Collision



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The momentum of a system before and after a collision

- Before the collision:

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- The momentum is only of mass *m* which is moving
- If the right is taken as the positive direction, the total momentum of the system is $\boldsymbol{m \times u}$

- After the collision:
 - Mass *M* also now has momentum
 - The velocity of *m* is now $-v$ (since it is now travelling to the left) and the velocity of *M* is *V*
 - The total momentum is now the momentum of *M* + momentum of *m*
 - This is $(M \times V) + (m \times -v)$ or $\boldsymbol{(M \times V) - (m \times v)}$

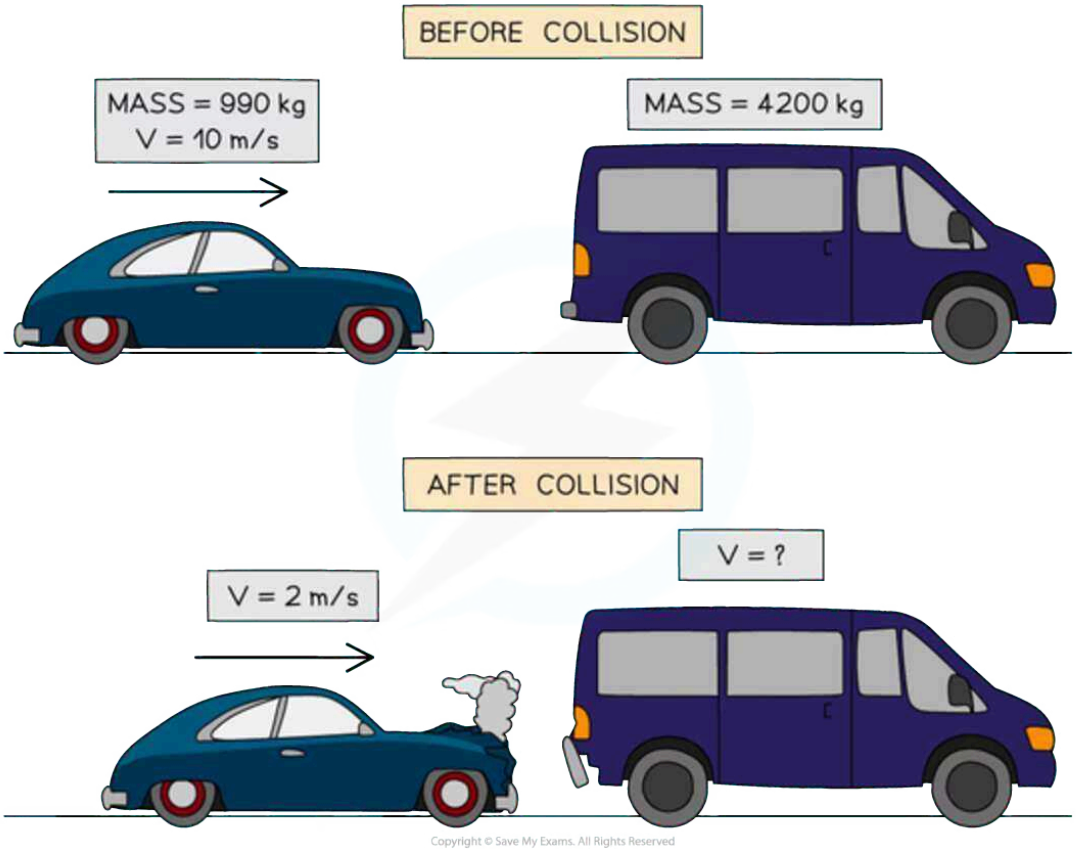

Your notes

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Your notes

Worked example

The diagram shows a car and a van, just before and just after the car collided with the van, which is initially at rest.



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Use the idea of conservation of momentum to calculate the velocity of the van when it is pushed forward by the collision.

Answer:

Step 1: State the principle of conservation of momentum

$$\text{total momentum before} = \text{total momentum after}$$

Step 2: Calculate the total momentum before the collision

$$p = mv$$

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Your notes

- Momentum of the car

$$p = 990 \times 10$$

$$p = 9900 \text{ kg m/s}$$

- Momentum of the van
 - The van is at rest
 - Therefore, $v = 0$ m/s
 - Therefore, $p = 0$ kg m/s
- Total momentum before collision

$$p_{before} = 9900 + 0 = 9900 \text{ kg m/s}$$

Step 3: Calculate the total momentum after the collision

- Momentum of the car

$$p = 990 \times 2$$

$$p = 1980 \text{ kg m/s}$$

- Momentum of the van

$$p = 4200 \times v$$

- Total momentum after collision

$$p_{after} = 1980 + 4200v$$

Step 4: Rearrange the conservation of momentum equation to solve for v

$$p_{before} = p_{after}$$

$$9900 = 1980 + 4200v$$

$$9900 - 1980 = 4200v$$

$$v = \frac{9900 - 1980}{4200}$$

$$v = 1.9 \text{ m/s}$$

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Exam Tip

If it is not given in the question already, drawing a diagram of before and after helps keep track of all the masses and velocities (and directions) in the conversation of momentum questions.

Your notes

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Impulse


Your notes

Impulse

- When a resultant (unbalanced) force acts on a mass, the momentum of that mass will change
- The **impulse of a force** is equal to that force multiplied by the time for which it acts:

impulse = force × change in time

impulse = $F\Delta t$

- The change in momentum of a mass is equal to the impulse provided by the force:

impulse = change in momentum

impulse = $F\Delta t = \Delta p$

- Change in momentum can also be described as:

$\Delta p = \Delta(mv)$

$\Delta p = mv - mu$

- Where:
 - m = mass in kg
 - v = final velocity in m/s
 - u = initial velocity in m/s
- Therefore:

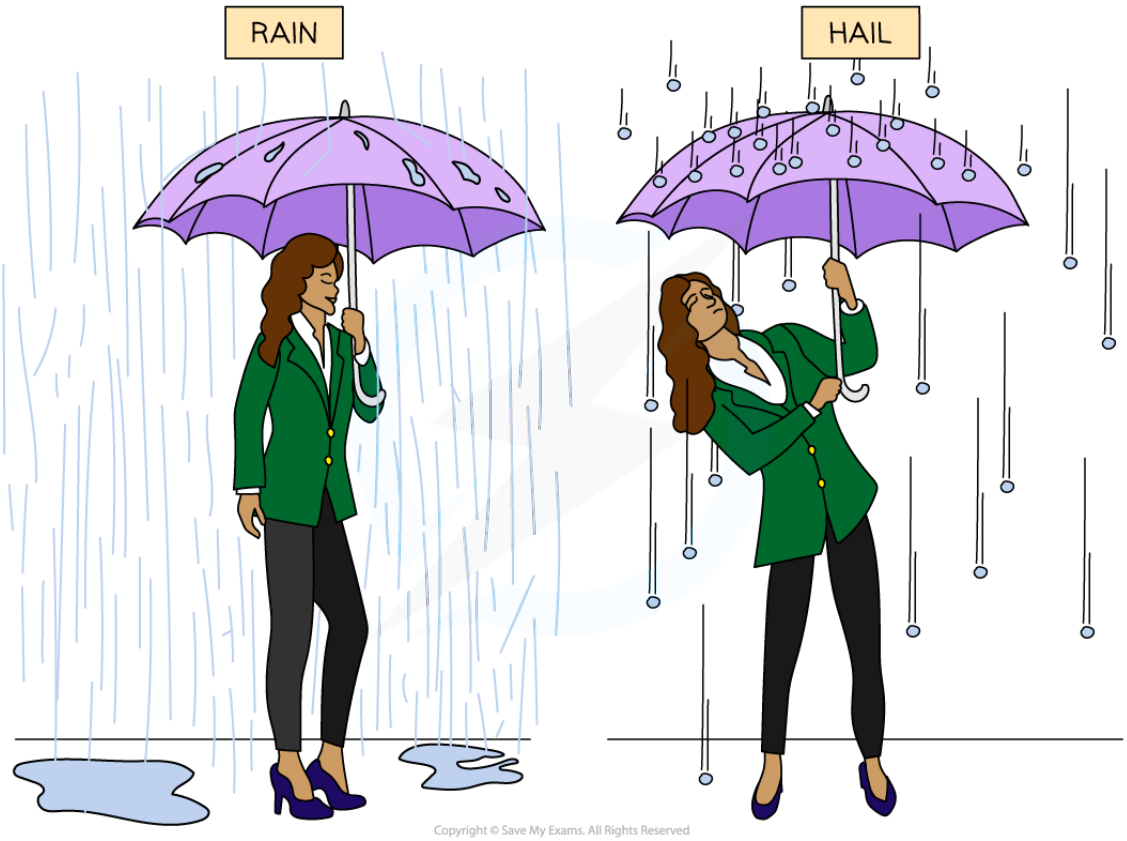
impulse = $F\Delta t = \Delta p = mv - mu$

- An example in everyday life of impulse is when standing under an umbrella when it is raining, compared to hail (frozen water droplets)
 - When rain hits an umbrella, the water droplets tend to splatter and fall off it and there is only a very **small** change in momentum
 - However, hailstones have a **larger mass** and tend to bounce back off the umbrella, creating a **greater** change in momentum
 - Therefore, the impulse on an umbrella is **greater** in hail than in rain
 - This means that **more force** is required to hold an umbrella upright in hail compared to rain

Impulse of Rain & Hail Stones

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Your notes



Since hailstones bounce back off an umbrella, compared to water droplets from rain, there is a greater impulse on an umbrella in hail than in rain

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Worked example

A 58 g tennis ball moving horizontally to the left at a speed of 30 m s^{-1} is struck by a tennis racket which returns the ball back to the right at 20 m s^{-1}.

(i) Calculate the impulse delivered to the ball by the racket
(ii) State which direction the impulse is in

Answer:

(i)

Step 1: **Write the known quantities**

- Taking the initial direction of the ball as positive (the left)
- Initial velocity, $u = 30$ m s^{-1}
- Final velocity, $v = -20$ m s^{-1}
- Mass, $m = 58$ g $= 58 \times 10^{-3}$ kg

Step 2: Write down the impulse equation

$$\text{Impulse } I = \Delta p = m(v - u)$$

Step 3: Substitute in the values

$$I = (58 \times 10^{-3}) \times (-20 - 30) = -2.9 \text{ N s}$$

(ii)

Direction of the impulse

- Since the impulse is negative, it must be in the opposite direction to which the tennis ball was initial travelling (since the left is taken as positive)
- Therefore, the direction of the impulse is to the right

Exam Tip

Remember that if an object changes direction, then this must be reflected by the change in sign of the velocity. As long as the magnitude is correct, the final sign for the impulse doesn't matter as long as it is consistent with which way you have considered positive (and negative). For example, if the left is taken as positive and therefore the right as negative, an impulse of 20 N s to the right is equal to -20 N s

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Force & Momentum


Your notes

- Force can also be defined as the **rate of change of momentum** on a body
- The change in momentum is defined as the final momentum minus the initial momentum
- These can be expressed as follows:

$$F = \frac{\Delta p}{\Delta t}$$

$$\Delta p = p_{final} - p_{initial}$$

- Where:
 - F = force in newtons (N)
 - Δ (Greek letter delta) = change in
 - p = momentum in kilogram metres per second (kg m/s)
 - t = time in seconds (s)

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Cambridge O Level Physics

Your notes

1.7 Energy, Work & Power

Contents

- Energy Stores & Transfers
- Kinetic Energy
- Gravitational Potential Energy
- Conservation of Energy
- Work
- Power
- Efficiency
- Energy Resources
- Energy from the Sun
- Energy from Fuels
- Energy from Water
- Geothermal Energy
- Energy from Wind

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Energy Stores & Transfers

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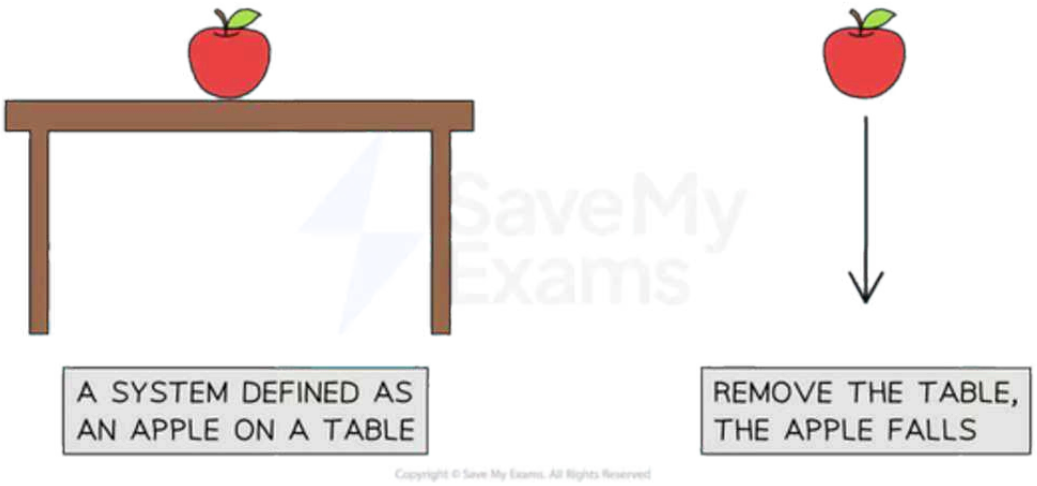
Energy Stores

- Energy is a property that must be transferred to an object to perform **work on** or **heat up** that object
 - Energy is measured in units of **joules (J)**
 - Energy will often be described as part of an energy **system**
- In physics, a system is defined as:

An object or group of objects

 - Defining the system, in physics, is a way of **narrowing** the parameters to **focus** only on what is relevant to the situation being observed
 - A system could be as **large** as the whole Universe, or as **small** as an apple sitting on a table
- When a system is in **equilibrium**, nothing changes, and so nothing happens
- When there is a **change** to a system, energy is **transferred**
 - If an apple sits on a table, and that table is suddenly removed, the apple will fall
 - As the apple falls, energy is transferred

Example of Energy Transfer



Energy is transferred when the apple is falling – the system is changing

- Energy is stored in objects in different **energy stores**

Descriptions of Energy Stores

Energy Store	Description

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Kinetic	Moving objects have energy in their kinetic store
Gravitational	Objects gain energy in their gravitational potential store when they are lifted through a gravitational field
Elastic	Objects have energy in their elastic potential store if they are stretched, squashed or bent
Magnetic	Magnetic materials interacting with each other have energy in their magnetic store
Electrostatic	Objects with charge (like electrons and protons) interacting with one another have energy in their electrostatic store
Chemical	Chemical reactions transfer energy into or away from a substance's chemical store
Nuclear	Atomic nuclei release energy from their nuclear store during nuclear reactions
Thermal	All objects have energy in their thermal store, the hotter the object, the more energy it has in this store



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Energy Transfers

Your notes

Energy is **transferred** between stores through different energy **transfer pathways**

- The energy transfer pathways are:
 - Mechanical
 - Electrical
 - Heating
 - Radiation
- These are described in the table below:

Energy Transfer Pathways Table

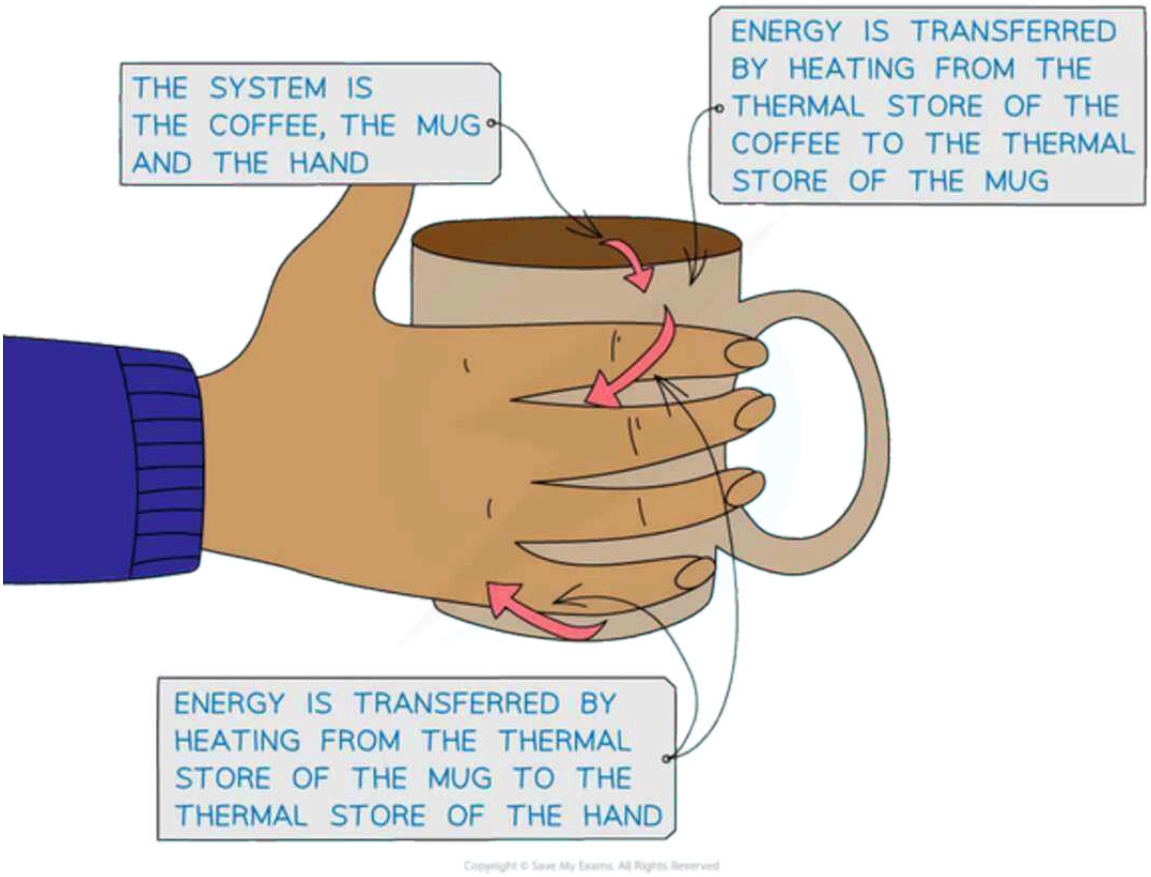
Transfer Pathway	Description
Mechanical working	When a force acts on an object (e.g. pulling, pushing, stretching, squashing)
Electrical working	A charge moving through a potential difference (e.g. current)
Heating (by particles)	Energy is transferred from a hotter object to a colder one (e.g. conduction)
(Heating by) radiation	Energy transferred by electromagnetic waves (e.g. visible light)

- An example of an energy transfer by heating is a hot coffee heating up cold hands

Energy Transfers Scenario

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Energy is transferred by heating from the hot coffee to the mug, to the cold hands

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Worked example

Describe the energy transfers in the following scenarios:

a) A battery powering a torch

b) A falling object

Answer:

a)

Step 1: Determine the store that energy is being transferred away from, within the parameters described by the defined system

- For a battery powering a torch
- The system is defined as the energy transfer from the battery to the torch, so this is the transfer to focus on
- Therefore, the energy began in the chemical store of the cells of the battery

Step 2: Determine the store that energy is transferred to, within the parameters described by the defined system

- When the circuit is closed, the bulb lights up
- Therefore, energy is transferred to the thermal store of the bulb
- Energy is then transferred from the bulb to the surroundings, but this is not described in the parameters of the system

Step 3: Determine the transfer pathway

- Energy is transferred by the flow of charge around the circuit
- Therefore, the transfer pathway is electrical

Energy is transferred **electrically** from the **chemical store** of the battery to the **thermal store** of the bulb

b)

Step 1: Determine the store that energy is being transferred away from, within the parameters described by the defined system

- For a falling object
- In order to fall, the object must have been raised to a height
- Therefore, it began with energy in its gravitational potential store

Step 2: Determine the store that energy is transferred to, within the parameters described by the defined system

- As the object falls, it is moving

Your notes

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- Therefore, energy is being transferred to its kinetic store

Step 3: Determine the transfer pathway

- For an object to fall, a resultant force must be acting on it, and that force is weight, and it acts over a distance (the height of the fall)
- Therefore, the transfer pathway is mechanical

Energy is transferred from the **gravitational store** to the **kinetic store** of the object via a **mechanical** transfer pathway

Exam Tip

Don't worry too much about the parameters of the system. They are there to help you keep your answers concise so you don't end up wasting time in your exam.

If you follow any process back far enough, you would get many energy transfers taking place. For example, an electric kettle heating water. The relevant energy transfer is from the thermal store of the kettle to the thermal store of the water, with some energy dissipated to the surroundings. But you could take it all the way back to how the electricity was generated in the first place. This is beyond the scope of the question. Defining the system gives you a starting point and a stopping point for the energy transfers you need to consider.


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Kinetic Energy

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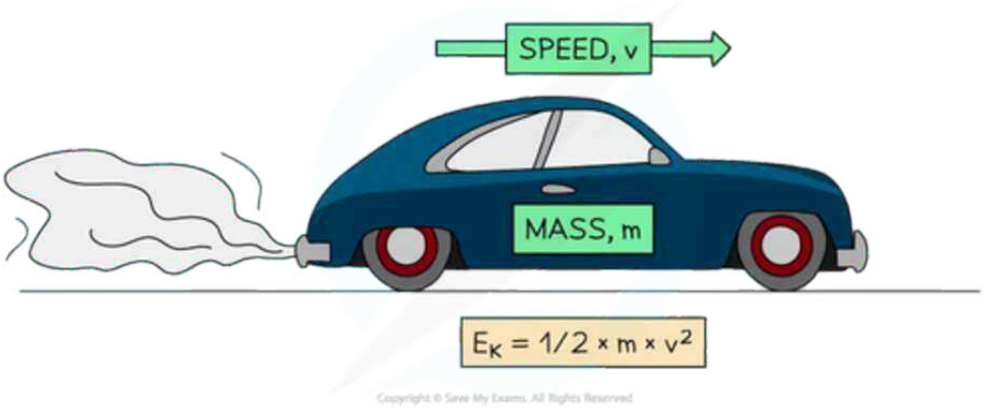
Kinetic Energy

- Energy in an object's kinetic store is defined as:

 The amount of energy an object has as a result of its mass and speed

- This means that any object in **motion** has energy in its kinetic energy store

Object in Motion



This car has mass and is not stationary, so there is energy in its kinetic store

- Kinetic energy can be calculated using the equation:

$$E_K = \frac{1}{2} \times m \times v^2$$

- Where:
 - E_K = kinetic energy in joules (J)
 - m = mass of the object in kilograms (kg)
 - v = speed of the object in metres per second (m/s)

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Worked example

Calculate the kinetic energy stored in a vehicle of mass 1200 kg moving at a speed of 27 m/s.

Answer:

Step 1: List the known quantities

- Mass of the vehicle, m = 1200 kg
- Speed of the vehicle, v = 27 m/s

Step 2: Write down the equation for kinetic energy

$$E_K = ½ mv^2$$

Step 3: Calculate the kinetic energy

$$E_K = ½ \times 1200 \times (27)^2$$

$$E_K = 437\,400 \text{ J}$$

Step 4: Round the final answer to 2 significant figures

$$E_K = 440\,000 \text{ J}$$

Exam Tip

When performing calculations using the kinetic energy equation, always double-check that you have squared the speed. Forgetting to do this is the most common mistake that students make.

Your notes

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Gravitational Potential Energy


Your notes

Gravitational Potential Energy

- Energy in the gravitational potential store of an object is defined as:

The energy an object has due to its height in a gravitational field

- This means:
 - If an object is lifted up, energy will be transferred **to** its gravitational store
 - If an object falls, energy will be transferred **away from** its gravitational store
- The gravitational potential energy of an object can be calculated using the equation:

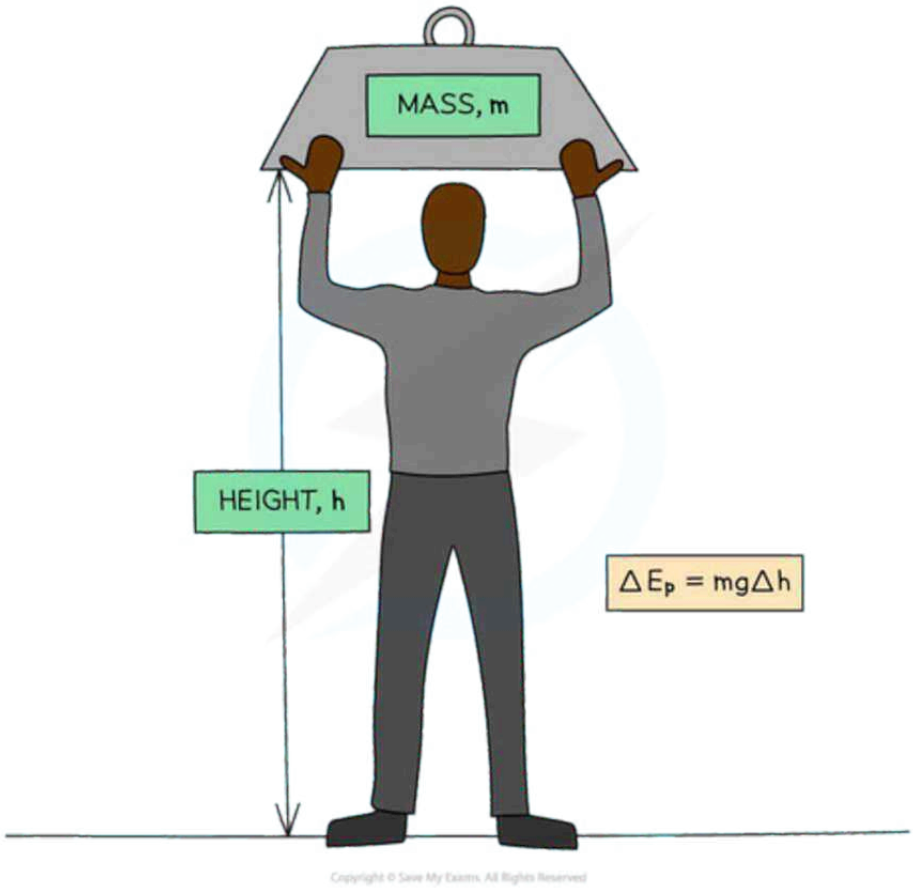
$$\Delta E_p = mg\Delta h$$

- Where:
 - ΔE_p = change in gravitational potential energy, in joules (J)
 - m = mass, in kilograms (kg)
 - g = gravitational field strength in newtons per kilogram (N/kg)
 - Δh = change in height in metres (m)

Energy in the Gravitational Potential Store

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Your notes



Energy is transferred to the mass's gravitational store as it is lifted above the ground

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Worked example

A man of mass 70 kg climbs a flight of stairs that is 3 m higher than the floor. Gravitational field strength is approximately 9.8 N/kg. Calculate the energy transferred to the man's gravitational potential energy store.

Answer:

Step 1: List the known quantities

- Mass of the man, $m = 70$ kg
- Gravitational field strength, $g = 9.8$ N/kg
- Height, $\Delta h = 3$ m

Step 2: Write down the equation for gravitational potential energy

$$\Delta E_P = mg\Delta h$$

Step 3: Calculate the gravitational potential energy

$$\Delta E_P = 70 \times 9.8 \times 3$$

$$\Delta E_P = \mathbf{2058\ J}$$


Your notes

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Conservation of Energy


Your notes

Conservation of Energy

- The **principle of conservation of energy** states that:

 Energy cannot be created or destroyed, it can only be transferred from one store to another

- This means that for a closed system, the total amount of energy is **constant**
- The **total** amount of energy transferred **into** the system must be **equal** to the **total** amount of energy transferred **away** from the system
- Therefore, energy cannot be 'lost', but it can be transferred to the surroundings
 - Energy can be **dissipated** (spread out) to the surroundings by heating and radiation
 - Dissipated energy transfers are often not **useful**, in which case they can be described as **wasted** energy

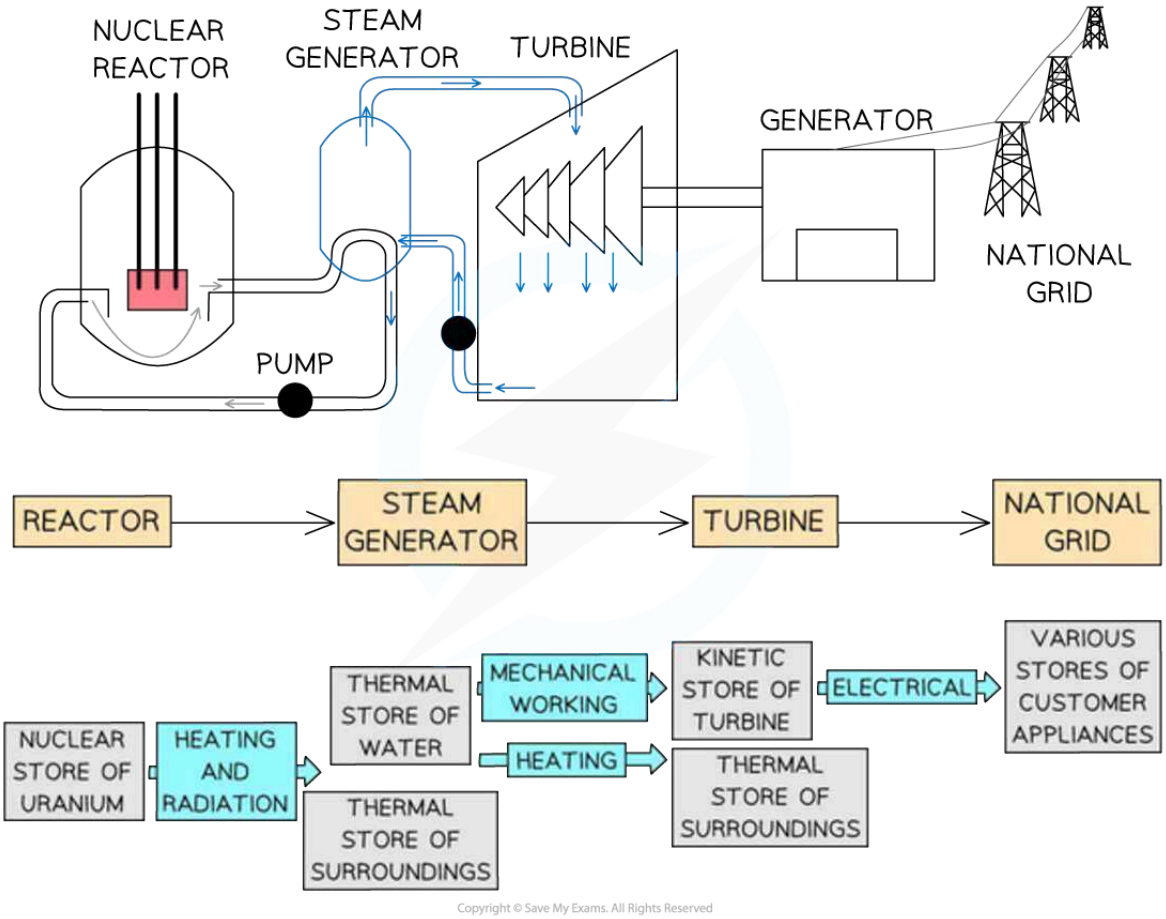
Energy Flow Diagrams

- Energy stores and transfers can be represented using a flow diagram
 - This shows both the stores and the transfers taking place within a system

Energy Transfers in a Nuclear Power Plant

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Energy flow diagram showing energy stores and transfers in a nuclear power plant. Note the colour difference of the labels (stores) and the arrows (transfer pathways)

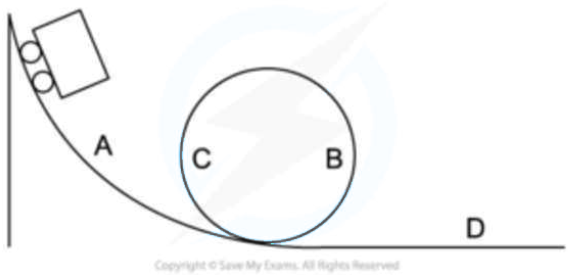
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Worked example

The diagram shows a rollercoaster going down a track.

The rollercoaster takes the path A → B → C → D.



Which statement is true about the energy changes that occur for the rollercoaster down this track?

A. $E_K \rightarrow \Delta E_P \rightarrow \Delta E_P \rightarrow E_K$

B. $E_K \rightarrow \Delta E_P \rightarrow E_K \rightarrow \Delta E_P$

C. $\Delta E_P \rightarrow E_K \rightarrow E_K \rightarrow \Delta E_P$

D. $\Delta E_P \rightarrow E_K \rightarrow \Delta E_P \rightarrow E_K$

ANSWER: D

- **At point A:**
 - The rollercoaster is raised above the ground, therefore it has energy in its **gravitational potential store**
 - As it travels down the track, energy is transferred **mechanically** to its **kinetic store**

- **At point B:**
 - Energy is transferred **mechanically** from the kinetic store to the **gravitational potential store**
 - As the kinetic energy store **empties**, the gravitational potential energy store **fills**

- **At point C:**
 - Energy is transferred **mechanically** from the gravitational potential store to the **kinetic store**

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Your notes

- **At point D:**
 - The flat terrain means there is no change in the amount of energy in its gravitational potential store, the rollercoaster only has energy in its **kinetic store**
 - The kinetic energy store is full

- In reality, some energy will also be transferred to the thermal energy store of the tracks due to **friction**, and to the thermal energy store of the surroundings due to **sound**

- We say this energy is **dissipated to the surroundings**
 - The total amount of energy in the system will be constant
 - Total energy in = total energy out

Exam Tip

It is helpful to think of energy stores as beakers and the total energy in the system as water. The water can be poured from one beaker into another back and forth as energy is transferred between stores.

You may not always be given the energy transfers happening in the system in exam questions. By familiarising yourself with the energy stores and transfer pathways, you will be able to relate these to the situation in the question. For example, a ball rolling down a hill is transferring energy from the ball's gravitational potential energy store to its kinetic energy store mechanically, whilst a spring transfers energy from its elastic potential energy store to its kinetic energy store mechanically.

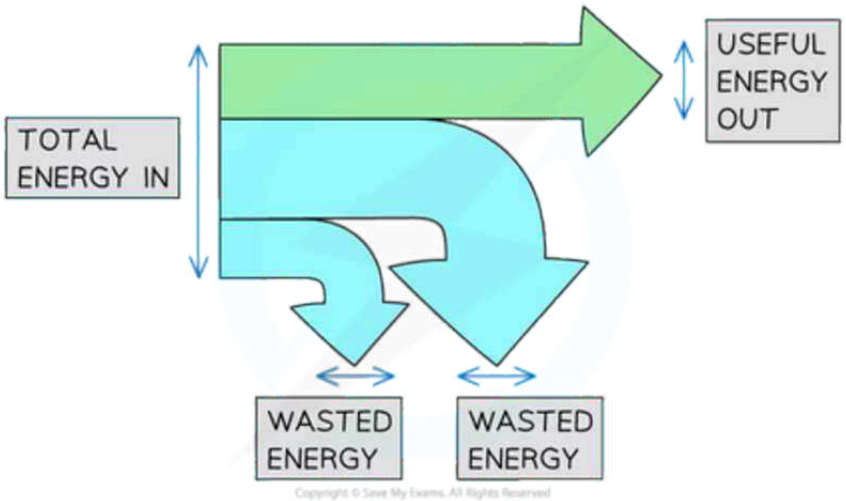
Sankey Diagrams

- **Sankey diagrams** can be used to represent energy transfers
 - Sankey diagrams are characterised by the splitting arrows that show the proportions of the energy transfers taking place

- The different parts of the arrow in a Sankey diagram represent the different energy transfers:
 - The left-hand side of the arrow (the flat end) represents the energy transferred **into** the system
 - The straight arrow pointing to the right represents the energy that ends up in the desired store; this is the **useful energy output**
 - The arrows that bend away represent the **wasted energy**

Sankey Diagram of Energy In and Energy Out

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Total energy in, wasted energy and useful energy out shown on a Sankey diagram

- The width of each arrow is proportional to the amount of energy being transferred
- As a result of the conversation of energy:

Total energy in = Useful energy out + Wasted energy

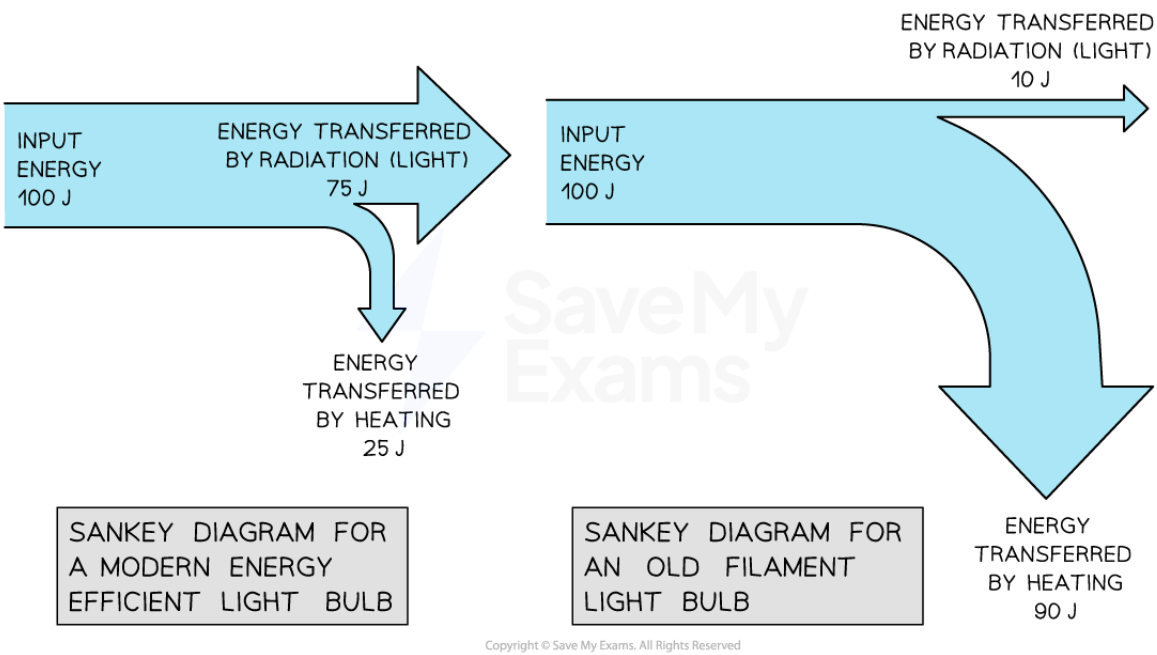
- A Sankey diagram for a modern efficient light bulb will look very different from that for an old filament light bulb
- A more efficient light bulb has **less** wasted energy
 - This is shown by the smaller arrow downwards representing the heat energy

Sankey Diagrams showing Different Efficiencies

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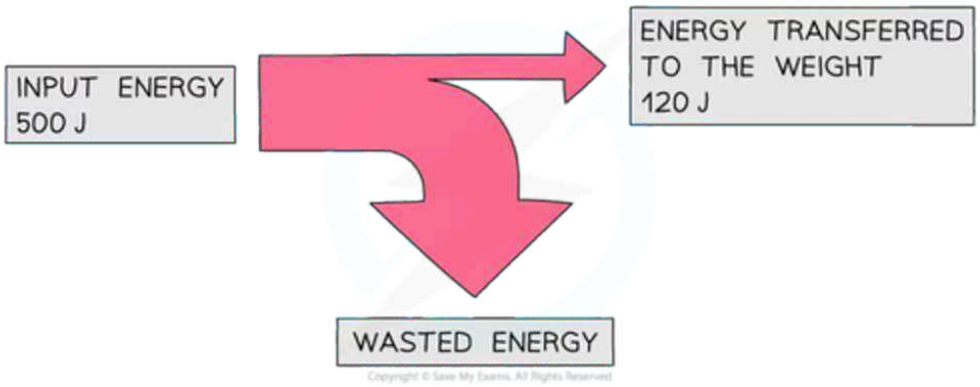
Sankey diagram for modern vs. old filament light bulb

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Your notes

Worked example

An electric motor is used to lift a weight. The diagram represents the energy transfers in the system.



Calculate the amount of wasted energy.

Answer:

Step 1: State the conservation of energy

- Energy cannot be created or destroyed, it can only be transferred from one store to another
- This means that:

Total energy in = Useful energy out + Wasted energy

Step 2: Rearrange the equation for the wasted energy

Wasted energy = Total energy in – Useful energy out

Step 3: Substitute the values from the diagram

500 – 120 = **380 J**

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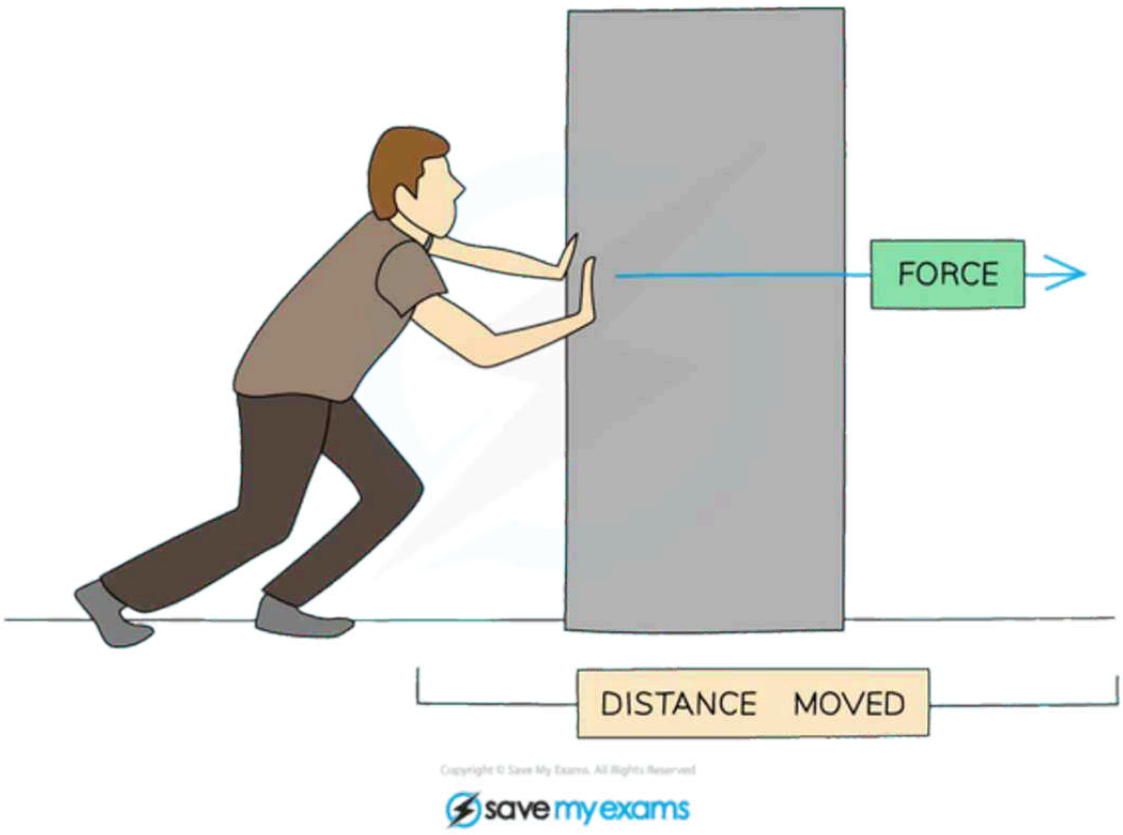
Work

Your notes

Work Done & Energy Transfers

- Work is done when an object is moved over a **distance** by a **force** applied in the **direction** of its displacement
 - It is said that the **force does work** on the object
 - If a force is applied to an object but doesn't result in any movement, no work is done

Work Done on an Object



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Work is done when a force is used to move an object

- The formula for work done is:

Work done = force × distance

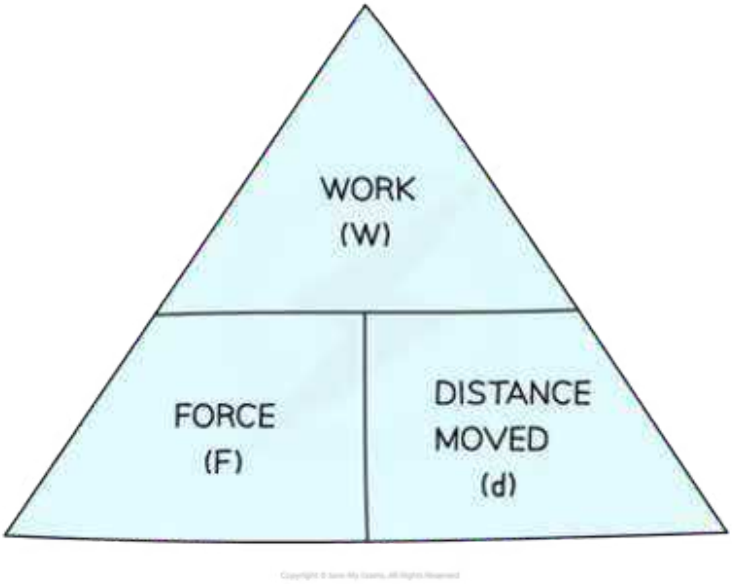
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$$W = Fd$$

Your notes

- Where:
 - W = work done in joules (J) or newton-metres (N m)
 - F =force in newtons (N)
 - d = distance in metres (m)
- You can rearrange this equation with the help of the formula triangle:

Formula Triangle for Work Done



Use the formula triangle to help you rearrange the equation

- Multiplying force and distance produces units of newton-metres (N m)
 - Work is measured in joules (J)
- This leads to a simple conversion:

1 J = 1 N m

- One joule is equal to the work done by a force of one newton acting through one metre
- Therefore, the number of joules is equal to the number of newton-metres, making conversions between the units very straightforward, for example:

1000 J = 1000 N m

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Your notes

- Whenever any **mechanical work** is done, energy is transferred **mechanically** from one store to another
- The amount of energy transferred (in joules) is equal to the work done (in joules or newton-metres)

energy transferred (J) = work done (J)

- If a force acts **in the direction** that an object is moving, then the object will **gain energy** (usually to its kinetic energy store)
- If the force acts in the **opposite direction** to the movement then the object will **lose energy** (dissipated to the surroundings usually by heating)

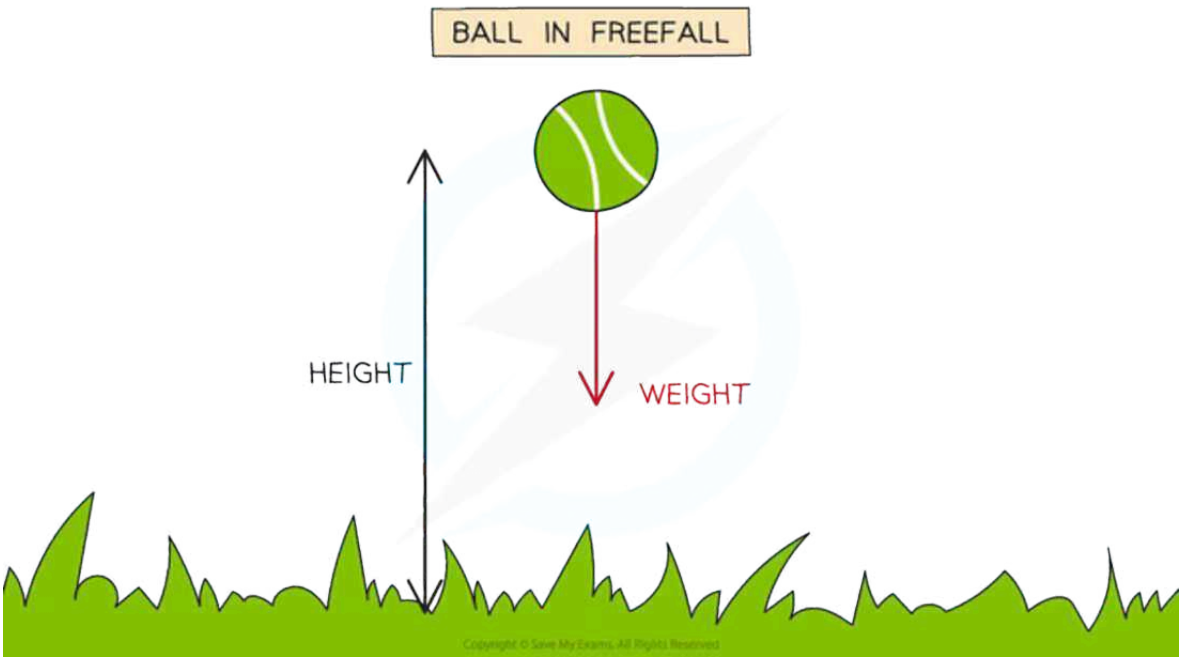
- Therefore:

$$W = Fd = \Delta E$$

Examples of Work

- Work is done on a ball when it is lifted to a height
 - The energy is transferred mechanically from the ball's kinetic energy store to its gravitational potential energy store

Weight Force Doing Work on a Ball



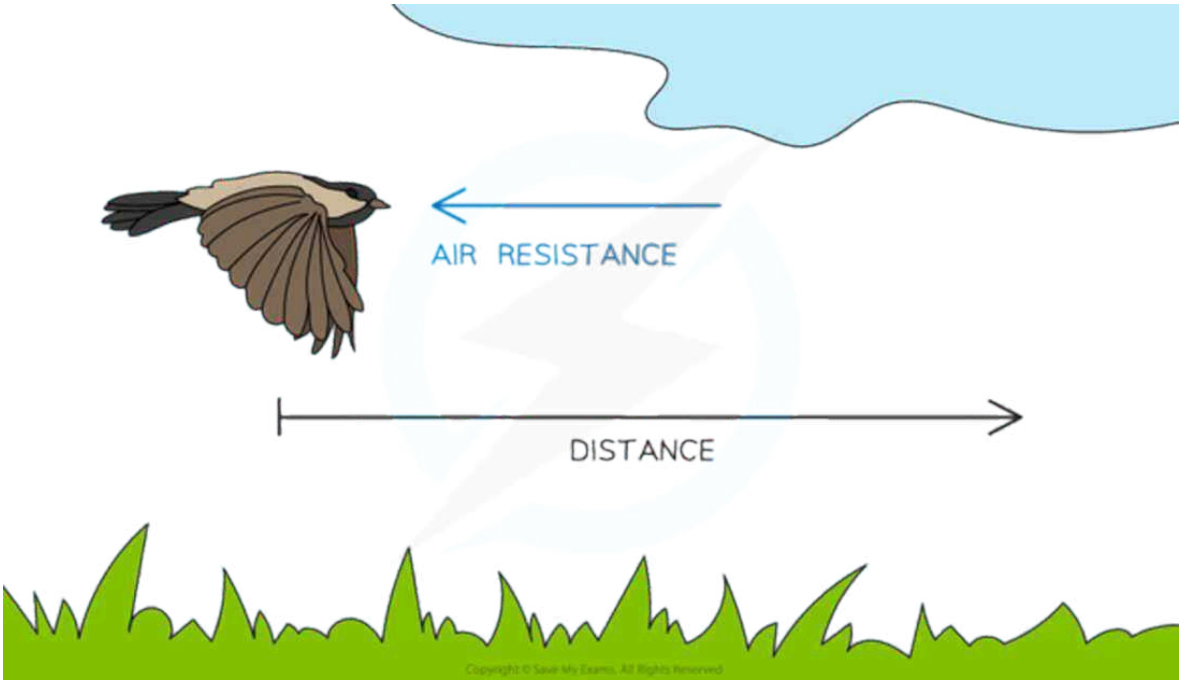
The weight on the ball produced by the gravitational field does work on the ball over a distance

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Your notes

- Work is done when a bird flies through the air
 - The bird must travel against air resistance, therefore energy is transferred from the bird's **kinetic store** to its **thermal store** and **dissipated** to the **thermal store** of the surroundings

Work Done Opposing Motion



Air resistance (drag) does work against the bird as it flies through the air

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Worked example

A car moving at speed begins to apply the brakes. The brakes of the car apply a force of 500 N which brings it to a stop after 23 m.



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Calculate the work done by the brakes in stopping the car.

Answer:

Step 1: List the known quantities

- Distance, $d = 23$ m
- Force, $F = 500$ N

Step 2: Write out the equation relating work, force and distance

$$W = F \times d$$

Step 3: Calculate the work done on the car by the brakes

$$W = 500 \times 23$$

$$W = \mathbf{11\,500\ J}$$

Exam Tip

Remember to always convert the distance into **metres** and force into n**ewtons** so that the work done is in **joules** or **newton-metres**

Your notes

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Power

Your notes

Power

- Machines, such as car engines, transfer energy from one energy store to another constantly over a period of **time**
- The **rate** of this energy transfer, or the rate of work done, is called **power**
- **Time** is an important consideration when it comes to **power**
- Two cars transfer the **same amount of energy**, or do the **same amount of work** to accelerate over a distance
- If one car has **more power**, it will transfer that energy, or do that work, in a **shorter amount of time**

Vehicles with Different Powers



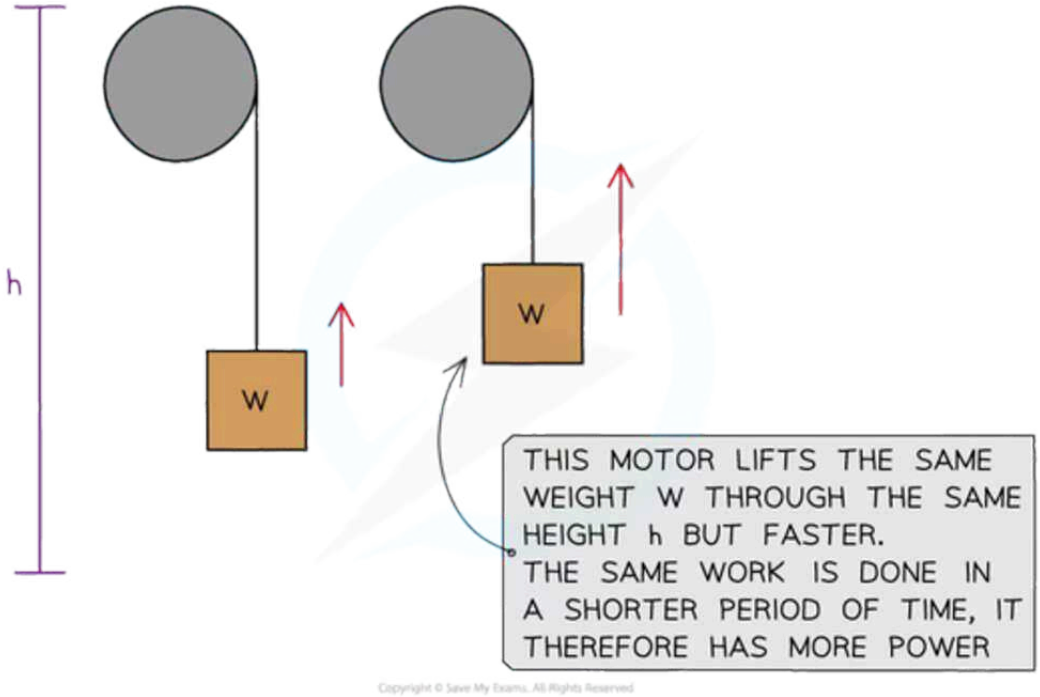
Two cars accelerate to the same final speed, but the one with the most power will reach that speed sooner.

- Two electric motors:
 - lift the same weight
 - by the same height
 - but one motor lifts it **faster** than the other
- The motor that lifts the weight faster has more **power**

Two Motors with Different Powers

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Your notes



Power is the rate of transfer of energy, or rate of work done. The higher power motor will do the same work in a shorter time.

- **Power ratings** are given to appliances to show the amount of energy transferred per unit time
- Common power ratings are shown in the table below:

Power Rating Table

Appliance or Object	Power rating / W
Torch	1
Electric lightbulb	$100 = 1 \times 10^2$
Electric cooker	$10\,000 = 1 \times 10^4$
Railway engine	$1\,000\,000 = 1 \times 10^6$
Saturn V space rocket	$100\,000\,000 = 1 \times 10^8$

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Very large power station	$10\,000\,000\,000 = 1 \times 10^{10}$
World demand for power	$10\,000\,000\,000\,000 = 1 \times 10^{13}$
A star similar to the Sun	$100\,000\,000\,000\,000\,000\,000\,000\,000 = 1 \times 10^{26}$

Your notes

Calculating Power

- Since power is defined as

The rate of doing work

- And work is

Work done = energy transferred

- Then, power can be expressed in equation form as

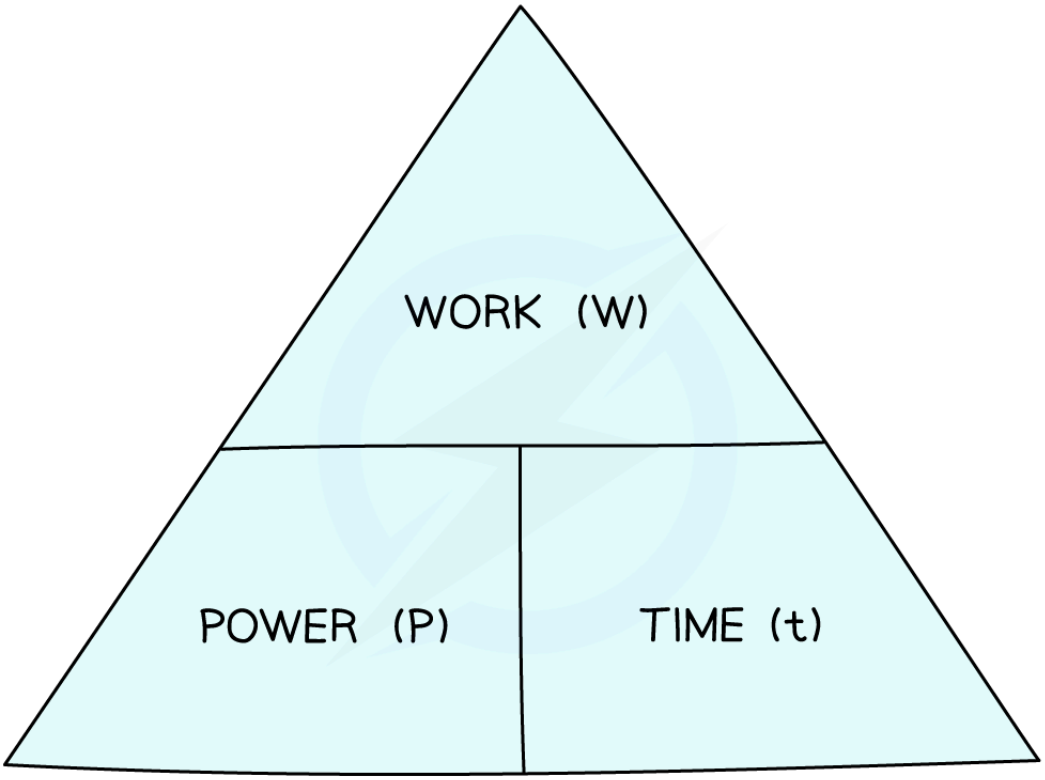
$$P = \frac{W}{t} \text{ or } P = \frac{\Delta E}{t}$$

- Where:
 - W or ΔE = The work done, or energy transferred, measured in **joules** (J)
 - t = time measured in seconds (s)
 - P = power measured in **watts** (W)
- Note that these two equations may be written slightly differently, but are representing the same thing - a transfer of energy over time
- This equation can be rearranged with the help of a formula triangle:

Formula Triangle for Power

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Your notes



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Work, power, time formula triangle

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Worked example

Calculate the energy transferred when an iron with a power rating of 2000 W is used for 5 minutes.

Answer:

Step 1: List the known values

- Power, $P = 2000$ W
- Time, $t = 5$ minutes $= 5 \times 60 = 300$ s

Step 2: Write down the relevant equation

$$P = \frac{\Delta E}{t}$$

Step 3: Rearrange for energy transferred, ΔE

$$\Delta E = P t$$

Step 4: Substitute in the known values

$$\Delta E = 2000 \times 300$$

$$\Delta E = 600\ 000\ \text{J}$$

Exam Tip

Think of power as "energy per second". Thinking of it this way will help you to remember the relationship between power and energy.

Your notes

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Efficiency

Your notes

Efficiency of Energy Transfer

- The **efficiency** of a system is a measure of the amount of **wasted energy** in an energy transfer

- Efficiency is defined as:

 The ratio of the useful power or energy output from a system to its total power or energy input

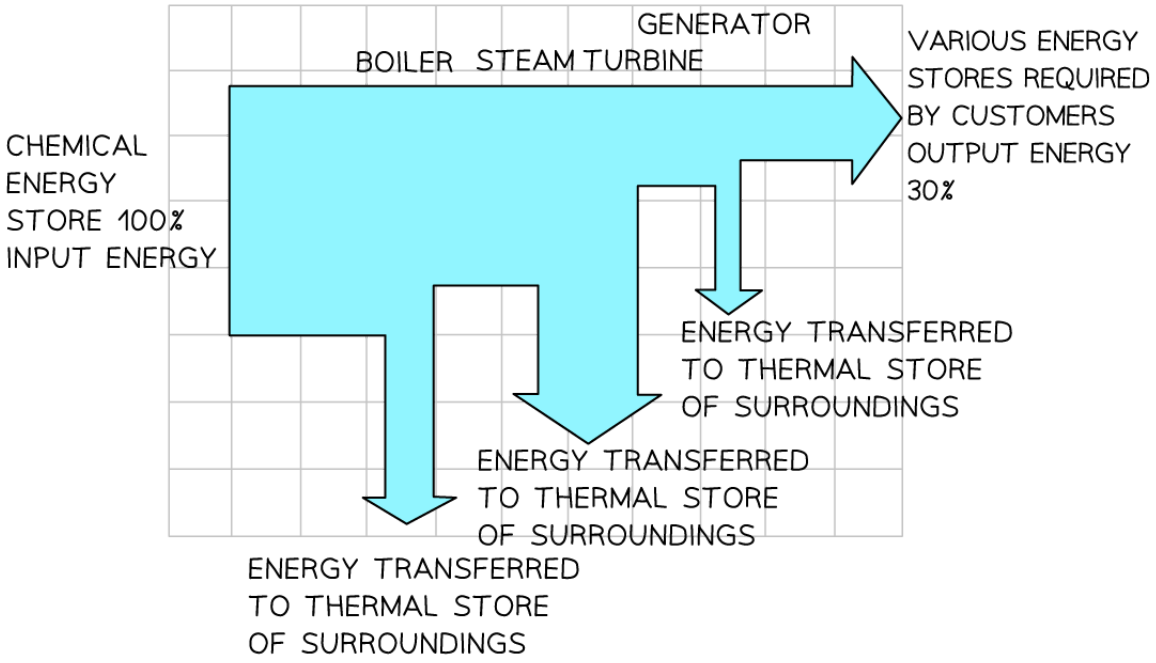
- If a system has **high** efficiency, this means most of the energy transferred is **useful**
- If a system has **low** efficiency, this means most of the energy transferred is **wasted**

- The overall efficiency of a typical thermal power station is approximately 30%
 - This means that 70% of the energy transferred from the power station to the National Grid is **wasted energy**

- In the production of electricity:
 - Energy is used to heat water to produce steam
 - The steam turns a turbine
 - The turbine turns a generator
 - The generator produces electricity
 - At each stage of this process, energy is dissipated to the surroundings

Sankey Diagram of a Power Station

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Sankey diagram showing the efficiency of a gas-fired power station

Calculating Efficiency

- Efficiency is represented as a percentage, and can be calculated using the equation:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

- The efficiency equation can also be written in terms of power:

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100\%$$

- Where power is defined as the energy transferred per unit of time

$$\square = \frac{\Delta \square}{\square}$$

Your notes

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Worked example

An electric motor has an efficiency of 35%. It lifts a 7.2 kg load through a height of 5 m in 3 s. Calculate the power of the motor.

Your notes

Answer:

Step 1: Write down the efficiency equation

$$\text{Efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100\%$$

Step 2: Rearrange to make power input the subject

$$\text{power input} = \frac{\text{power output}}{\text{efficiency} \div 100} \quad \text{OR}$$

$$\text{power input} = \frac{\text{power output} \times 100}{\text{efficiency}}$$

Step 3: Calculate the power output

$$\text{power output} = \frac{\Delta E}{t}$$

- ΔE is equal to the change in gravitational potential energy as the load is lifted

$$\Delta E_P = mg\Delta h$$

$$\Delta E_P = 7.2 \times 9.8 \times 5$$

$$\Delta E_P = 352.8 \text{ J}$$

$$\text{Therefore, power output} = \frac{352.8}{3}$$

$$\text{power output} = 117.6 \text{ W}$$

Step 4: Substitute the values into the power input equation

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$$\text{power input} = \frac{117.6}{0.35} \text{ OR power input} = \frac{117.6 \times 100}{35}$$

$$\text{power input} = 336 \text{ W}$$

Your notes

Exam Tip

Efficiency can be given in a ratio (between 0 and 1) or percentage format (between 0 and 100 %)

If the question asks for efficiency as a ratio, give your answer as a fraction or decimal.

If the answer is required as a percentage, remember to multiply the ratio by 100 to convert it:

- if the ratio = 0.25, percentage = 0.25 x 100 = 25 %

Remember that efficiency has **no units**

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Energy Resources

Your notes

Renewable & Non-renewable Energy Sources

- **Non-renewable** energy sources are **finite** and will run out. These include:
 - Fossil fuels
 - Nuclear
- **Renewable energy** sources are **infinite** and will not run out. These include:
 - Hydroelectric
 - Wave/tidal
 - Wind
 - Solar
 - Geothermal
 - Biomass/waste
- Once in place, except for biomass/waste, these renewable resources do **not** produce **any** greenhouse gas emissions
- Greenhouse gases may be emitted in the production, construction and transport of the equipment

Increase in Renewable Energy

- Renewable energy is increasingly important in the global energy mix
- This is due to:
 - Non-renewable fossil fuels will at some point run out and so they need to be replaced with another energy source
 - The use of non-renewable fuels is damaging to the environment.
 - Fossil fuels when burnt release greenhouse gases and the sulphur dioxide released causes acid rain
 - Mining and drilling for fossil fuels can destroy habitats and damage the surrounding environment
 - Increasing awareness of the impact of using fossil fuels has resulted in international pressure to reduce their use
 - Countries wanting to reduce their reliance on imports of energy sources and improve their energy security

Table of Renewable & Non-renewable energy sources

Energy Resource	Renewable?	Advantages	Disadvantages
Fossil Fuels	No	Reliable. Can produce large amounts of energy at fairly short notice.	Produces significant greenhouse gases and pollution.

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Nuclear	No	Reliable. Produces no greenhouse gases or pollution. A large amount of energy is produced from a small amount of fuel.	Produces dangerous radioactive waste that can take thousands of years to decay.
Bio-fuels	Yes	The CO_2 produced while burning the fuel is balanced by the CO_2 absorbed whilst producing it.	Can take up a lot of land and consume resources that are needed for food production.
Wind	Yes	Produces no greenhouse gases or pollution. Land can still be used for farming.	Not reliable. Turbines can be noisy and ugly. Not everywhere is suitable.
Hydroelectric	Yes	Reliable and can produce large amount of energy at short notice. Produces no pollution of greenhouse gases.	Can involve flooding large area, destroying important wildlife habitats
Tidal	Yes	The tides are very predictable, and a large amount of energy can be produced at regular intervals.	Very few suitable locations. Can cause environmental harm to estuaries and disrupt shipping
Geothermal	Yes	Reliable. Geothermal stations are usually small. Produces no greenhouse gases or pollution. Good for producing energy in remote places.	Can result in the release of harmful gases from underground. Not many places are suitable
Solar	Yes	Can involve flooding large area, destroying important wildlife habitats	Not reliable (only works when sunny). Solar farms can use up lots of farmland.

Your notes

Exam Tip

You must recognise the different types of energy sources, and whether they are renewable or non-renewable. You will be expected to justify each as well.

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Energy from the Sun


Your notes

Energy from the Sun

Most of our energy resources on the Earth come from the **Sun**:

- The Sun heats up the atmosphere, creating **wind** and producing **waves**
- Water evaporated by the Sun falls as rain, filling up **reservoirs**
- Plants grown using sunlight form the basis for fuels – both biofuels and fossil fuels

Some forms of energy, however, do not come from the **Sun**:

These include:

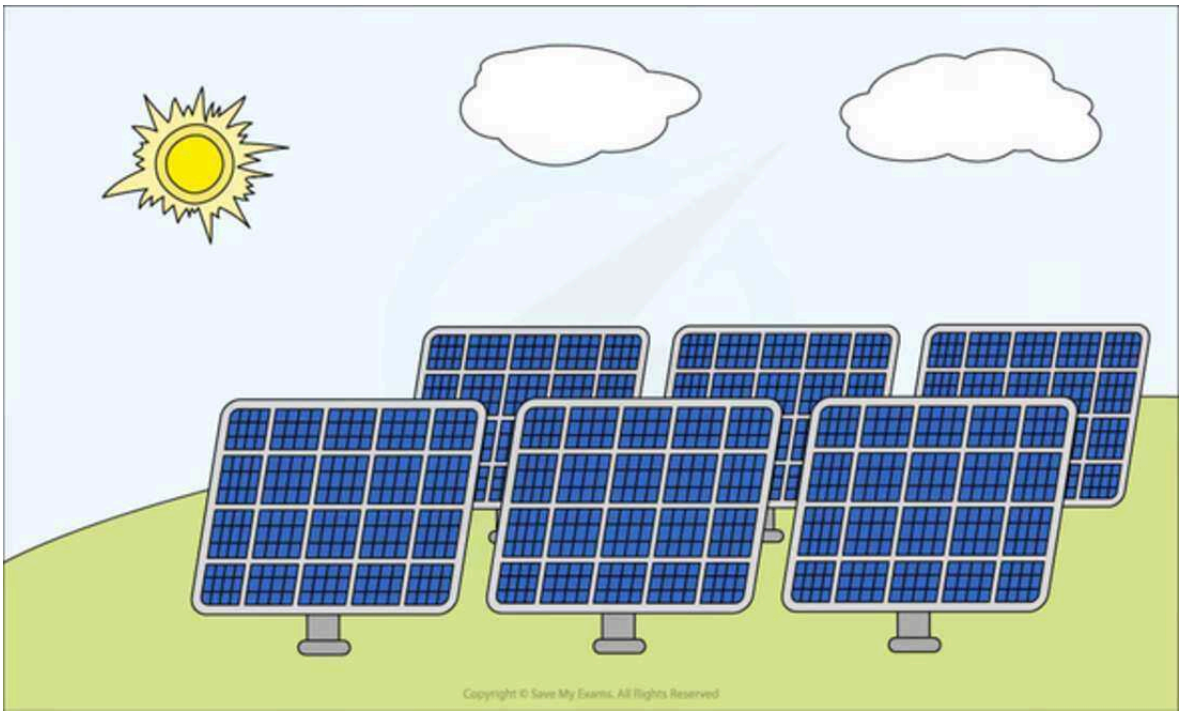
- **Geothermal** – this comes from heat produced in the Earth's core
- **Nuclear** – this comes from elements which make up a small proportion of the Earth's crust
- **Tidal** – this comes (mainly) from the gravitational attraction of the Moon

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- The energy from the Sun that falls on the Earth is transferred by radiation
 - Mostly **visible light** and **infrared radiation**
- The amount of energy transferred from the Sun to the Earth **each hour** is equal to the energy use of the world for **one year!**
- Therefore, scientists are working hard to find methods of harnessing this energy
 - Solar energy has a **low energy density**, which means large collecting devices are required
 - Collecting solar energy is **expensive** (due to the equipment required) and **inefficient**

- **Solar cells** transfer energy from sunlight electrically producing a current, and therefore generating **electricity**
 - Solar cells, sometimes called photovoltaic cells, are made of semiconducting materials
 - A number of cells connected together can supply electricity to homes, small-scale businesses, communication devices and satellites
 - Energy generated from solar cells can be stored in batteries for later use

Field of Solar Cells



Solar cells use energy from sunlight to produce electricity

Advantages

- Solar energy is a **renewable** resource

Your notes

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- In many places on Earth sunlight is a **reliable** energy resource (this means that the sun shines most of the time)
- Solar farms produce no **greenhouse gases** or **pollution**
- Solar energy can be generated in **remote places** where they don't have electricity
 - For example to power solar street signs in rural areas


Your notes

Disadvantages

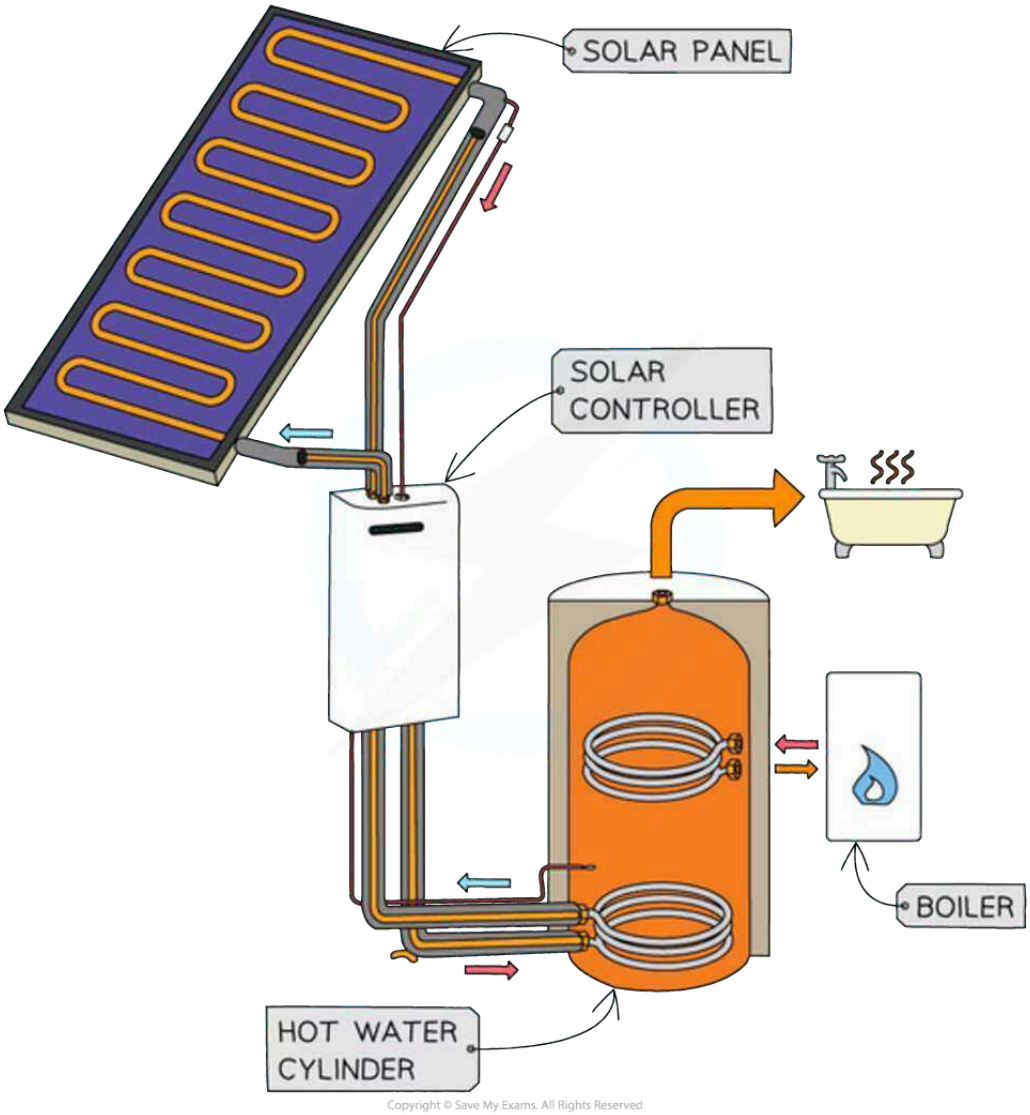
- Solar farms need to be **large scale** to produce large amounts of electricity
 - This is **expensive** to set up
 - People often don't like the appearance of large solar farms, this is known as **visual pollution**
- In many places on Earth sunlight is **not** a **reliable** energy resource (there are not enough sunshine-hours to justify the set-up costs)

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Your notes

- **Solar panels** transfer energy from sunlight to the thermal store of the solar panels which is used to **heat water** in the pipes
 - Solar panels can be used to warm domestic water supplies
 - This can reduce the cost of producing hot water since it is heated partially by the solar panels
 - **Solar furnaces** consist of large curved mirrors that focus the sun's rays on to a small area
 - These can be used to boil water, generating enough steam to turn turbines and generate electricity in a power station

Function of a Solar Panel



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Solar panels use energy from sunlight to heat water

- Water is **stored** in a water **tank** and pumped through small **pipes** running through the solar panel
- I**nfrared radiation** from the Sun heats the water in the pipes as it flows through them
- The water returns to the tank at a **higher temperature**
- Water may still need to be heated further to reach the desired temperature (eg. for a shower)

Advantages

- Solar energy is a **renewable** resource
- In many places on Earth sunlight is a **reliable** energy resource (this means that the sun shines most of the time)
- Solar panels produce no **greenhouse gases** or **pollution** once they are operating
- Solar panels can cut the cost of energy bills for households

Disadvantages

- Solar furnaces need to be large scale to produce high temperatures
- Energy is still needed to heat water to a higher temperature in domestic households
- In many places on Earth sunlight is **not** a **reliable** energy resource (the sun doesn't shine regularly enough to justify the set-up costs)


Your notes

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Energy from Fuels

Your notes

Fossil Fuels

- Fossil fuels are:
 - **Coal**
 - **Natural gas** (mostly methane) which is used in domestic boilers and cookers
 - Crude **oil** which is refined into petrol, diesel, and other fuels

Three Main Fossil Fuels



Fossil fuels: coal, oil and natural gas

- Fossil fuels are formed from the **remains of plants and animals**
- **Chemical energy** stored in fossil fuels originally came from **sunlight**
 - Energy from the sun was transferred to the chemical energy store of plants by photosynthesis (plants use energy from sunlight to make food)
 - Animals ate the plants and the energy was transferred to their chemical store

Advantages

- The current systems of transport and electricity generation rely heavily on fossil fuels which are generally readily **available** on a daily basis
- In the past fossil fuels have been **reliable** for large scale energy production although this is changing as supplies deplete and prices rise

Disadvantages

- It takes **millions of years** for fossil fuels to form
 - This is why they are considered to be a **non-renewable** energy resource

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- The increasing demand for a **decreasing supply** causes prices to increase
- Fossil fuels are predicted to **completely run out** within the next 200 years

- Burning fossil fuels pollutes the atmosphere with harmful gases such as:
 - **Carbon dioxide** which contributes to the **greenhouse effect**
 - **Sulphur dioxide** which produces **acid rain**
 - Both carbon and sulphur can be captured upon burning preventing it from being released into the atmosphere but this is expensive to do


Your notes

Uses of Fossil Fuels

- Fossil fuels are used for:
 - Transport
 - Generating electricity
 - Heating

Transport

- The majority of vehicles in the world are powered by **petroleum** products such as petrol, diesel and kerosene
 - These resources all originate from crude oil, which is a **fossil fuel**

- A growing number of vehicles are now being powered by **electricity**
 - The advantage of this is that while the vehicle is being driven, it produces **zero carbon emissions**
 - The disadvantage is that when the vehicle is being charged, it is connected to the National Grid, which currently uses a **combination** of renewable and non-renewable energy sources

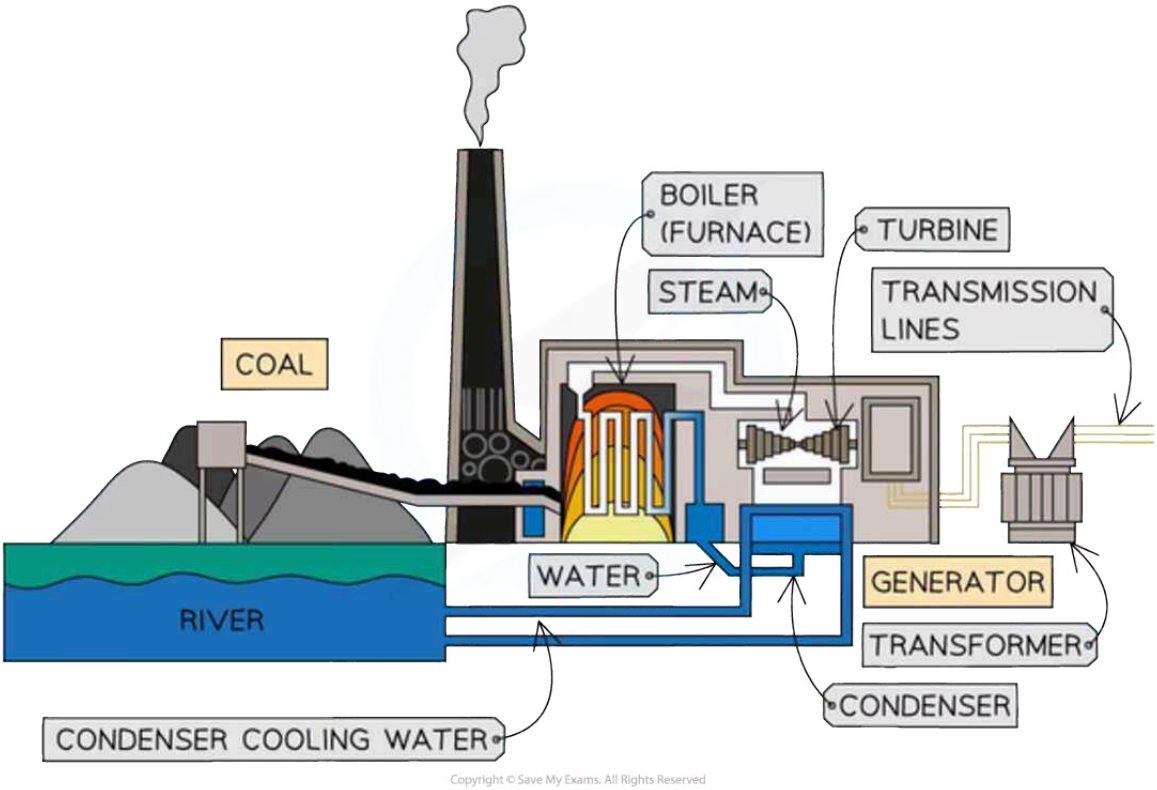
Electricity Generation

- Fossil fuels, such as coal and oil, are used to produce energy **on-demand** when energy is needed
 - This is done by **burning** the materials when the energy is required
 - When coal is burned, **energy** is released from its **chemical store**
- This is used to **boil water** creating **steam**
- Steam is forced around the system and this turns **a turbine**
- The turbine turns coils in a magnetic field in the generator
 - This generates **electricity**
- The electricity is transferred through a **step-up** transformer and is carried out of the system by **electrical lines**
- The steam within the turbine will cool and **condense** and then be pumped back into the boiler to **repeat the process**

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Your notes

A coal-fired power station

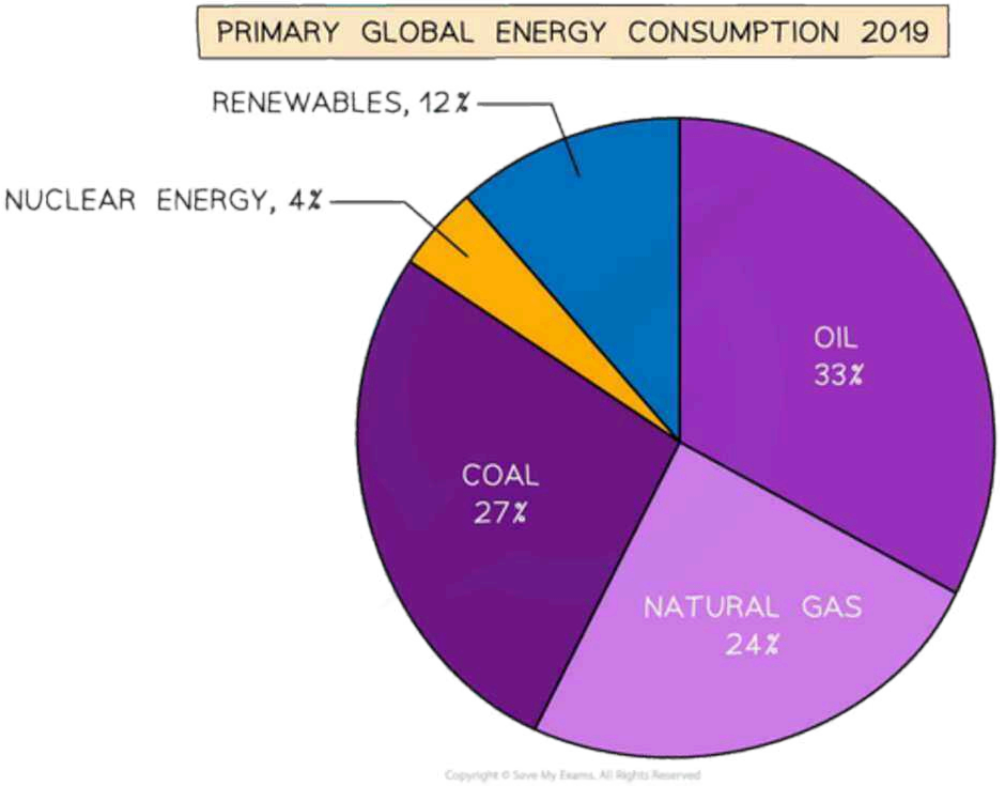


Electricity generation in a coal-fired power station

- Electricity plays a bigger role in people's lives than ever before
 - With almost 8 billion people in the world, this means the **demand** for electricity is **extremely high**
 - To keep up with this demand, a combination of **all** the energy resources available is needed
- On the downside, the majority (84%) of the world's energy is still produced by non-renewable, carbon-emitting sources
 - This has an enormous **negative** impact on the environment
 - Currently, scientists are working hard to develop more and more efficient ways to produce electricity using more carbon-neutral energy resources

Pie chart of global energy consumption

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Percentage of renewable and non-renewable energy consumption in 2019

Your notes

Heating

- Most homes in cold countries are fitted with **central heating systems**
 - These utilise **natural gas** in order to heat up water which can be pumped around radiators throughout the home

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Bio Fuels


Your notes

- Biofuels are made from plant matter
 - Energy from sunlight is transferred to the **chemical store** of plants
- **Ethanol** or **methane** can be produced and used in place of fossil fuels
 - However, they have only half the **energy density** of fossil fuels

Advantages

- Biofuel is a **renewable resource**
- Some vehicles can be powered by **biofuel** rather than using fossil fuels
- Biofuel is considered to be **carbon neutral**
- No sulphur dioxide is produced

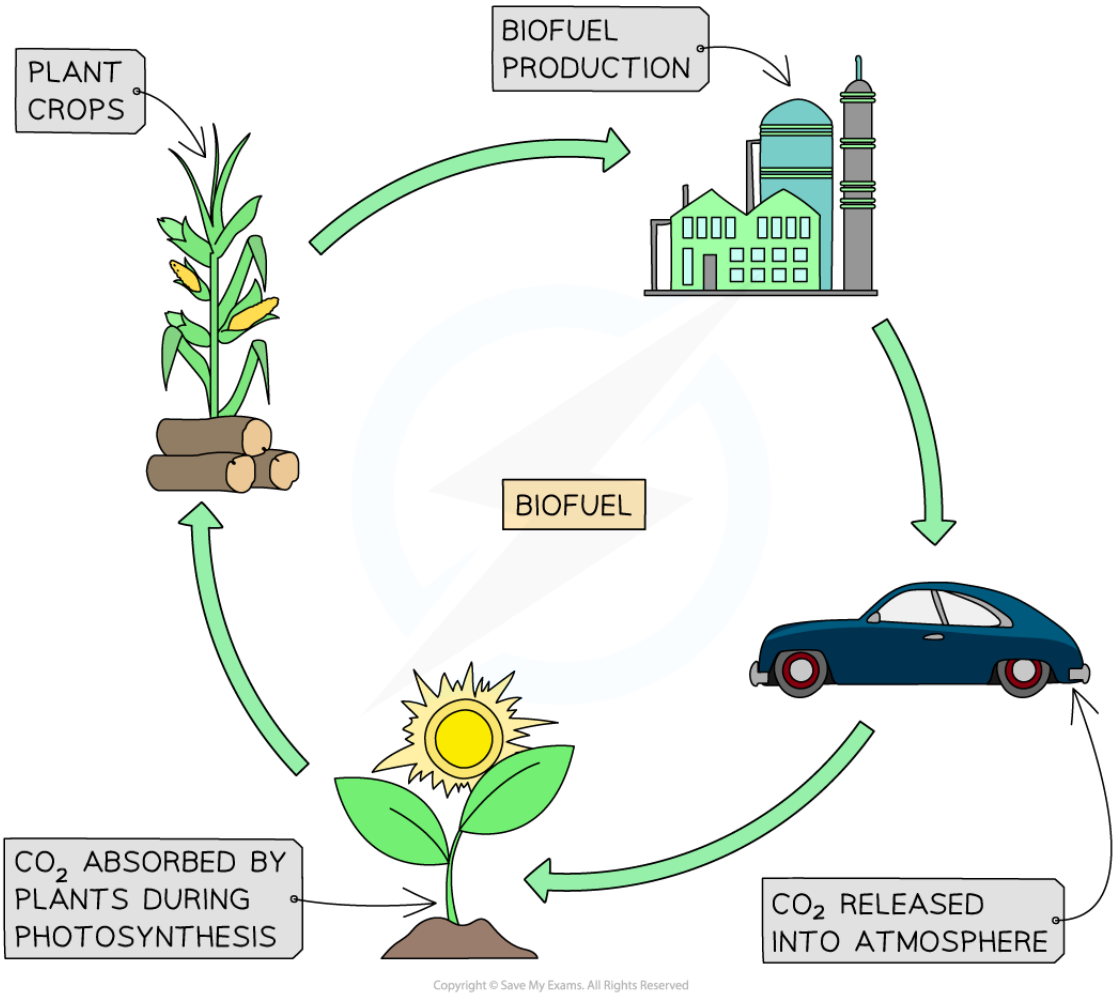
Disadvantages

- Crops of biofuel producing plants must be grown which takes **time**
 - Growing the crops takes a lot of **land**, and takes **resources** needed for food production
- Burning biofuels releases **carbon dioxide** into the atmosphere
 - It is considered carbon neutral because plants take in carbon dioxide when they photosynthesise

Cycle of Carbon used for Biofuel

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Your notes



Plants take in carbon dioxide during photosynthesis, but carbon dioxide is released back into the atmosphere when biofuels are burned

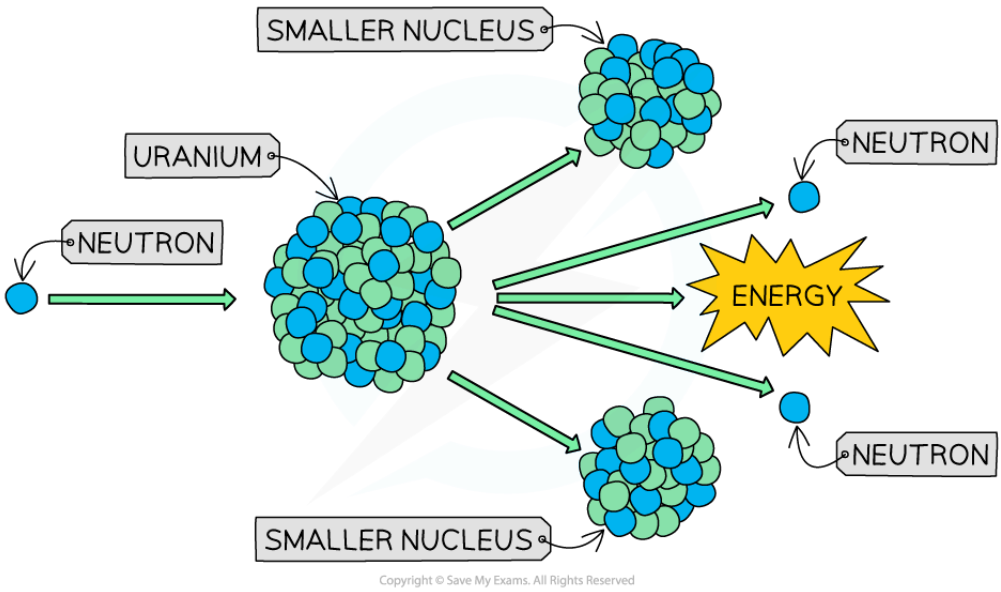
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Nuclear Fuel

Your notes

- Energy stored in the **nucleus** of atoms can be released when the nucleus is broken in two
 - This is known as nuclear **fission**

Process of Nuclear Fission



A large nucleus is broken into two smaller nuclei energy is released

- Nuclear power stations use fission reactions to **heat water**, to turn turbines to **generate electricity**

Advantages

- **No pollution** released into atmosphere
- Nuclear reactors are perfectly **safe** as long as they are functioning properly
 - Stringent checks must be routinely carried out and rigorous safety procedures followed
- Nuclear power stations can generate electricity **reliably** on a **large scale** which is **available** as needed
- There are extensive reserves of fissionable atoms
- A large amount of power is produced from a small amount of source

Disadvantages

- Uranium ore found in the ground is used for fission reactions and since there is a **finite supply**
 - Nuclear power is a **non-renewable** resource
- Nuclear fuels produce **radioactive waste**
 - Radioactive waste needs to be stored for thousands of years

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- Safe ways of storing radioactive waste is expensive
- If an accident occurs at a nuclear reactor, radioactive waste can leak out and spread over large areas and cause serious, long term damage to people and objects


Your notes

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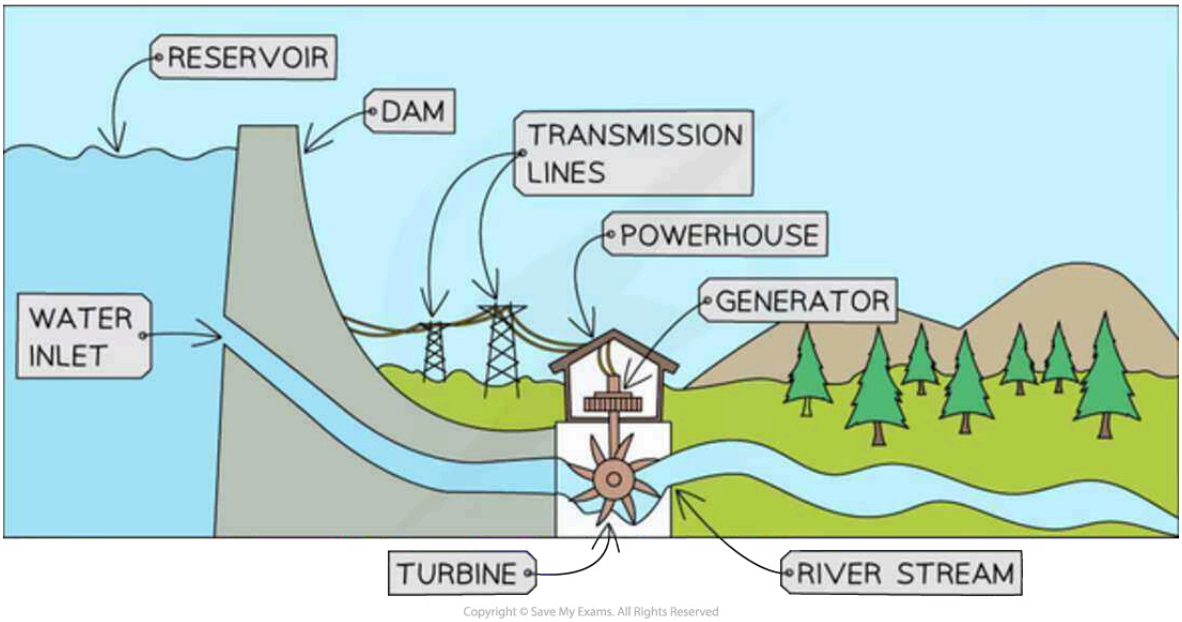
Energy from Water

Your notes

Hydroelectric Dams

- When water is stored above ground level it has energy in its **gravitational potential store**
- This energy can be transferred to **kinetic energy** if the water is allowed to flow down the slope
- Flowing water turns the turbine to **generate electricity**

A Hydroelectric Dam Operating



A hydroelectric dam transfers energy from the gravitational potential energy store of the water to its kinetic energy store mechanically to generate electricity

Advantages

- Can respond to demand so is **reliable** and **available**
- Can generate **large scale** amounts of electricity

Disadvantages

- Need to flood valleys to build which **destroys habitats, towns and villages**
- The pumping systems can release **large amounts of greenhouse gases**

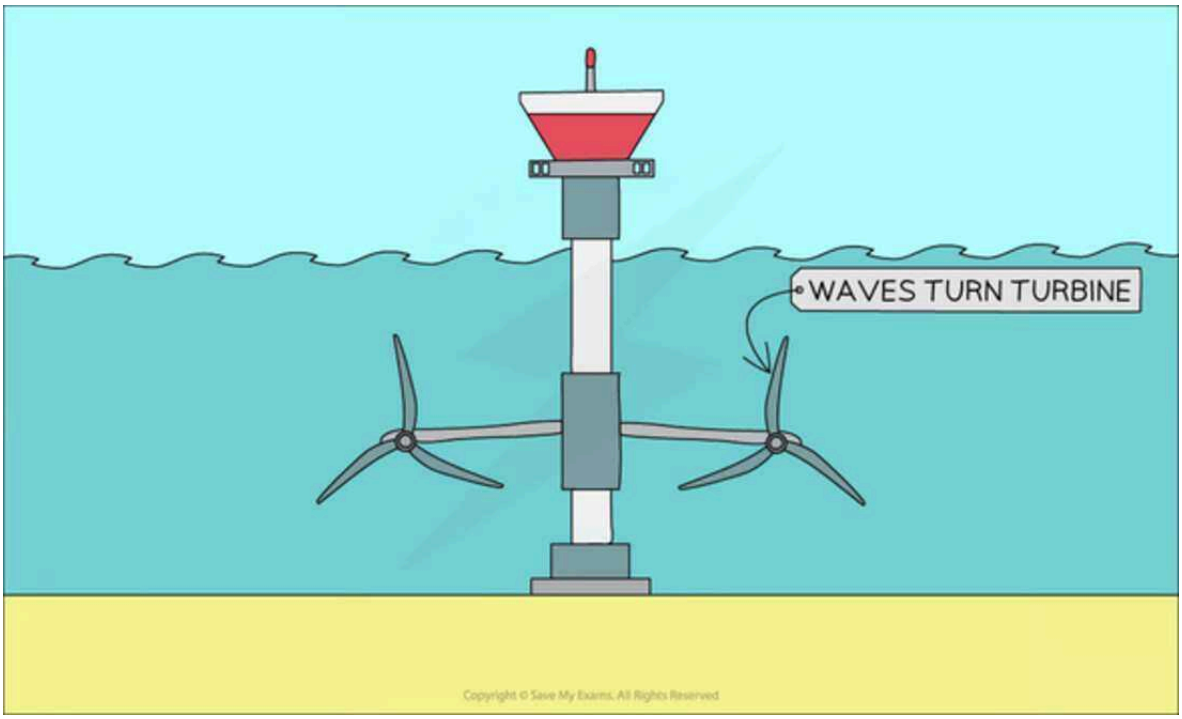
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Wave and Tide Power


Your notes

- The rise and fall of waves or the tide can be used to turn a turbine and generate electricity

Turbines using Wave Power

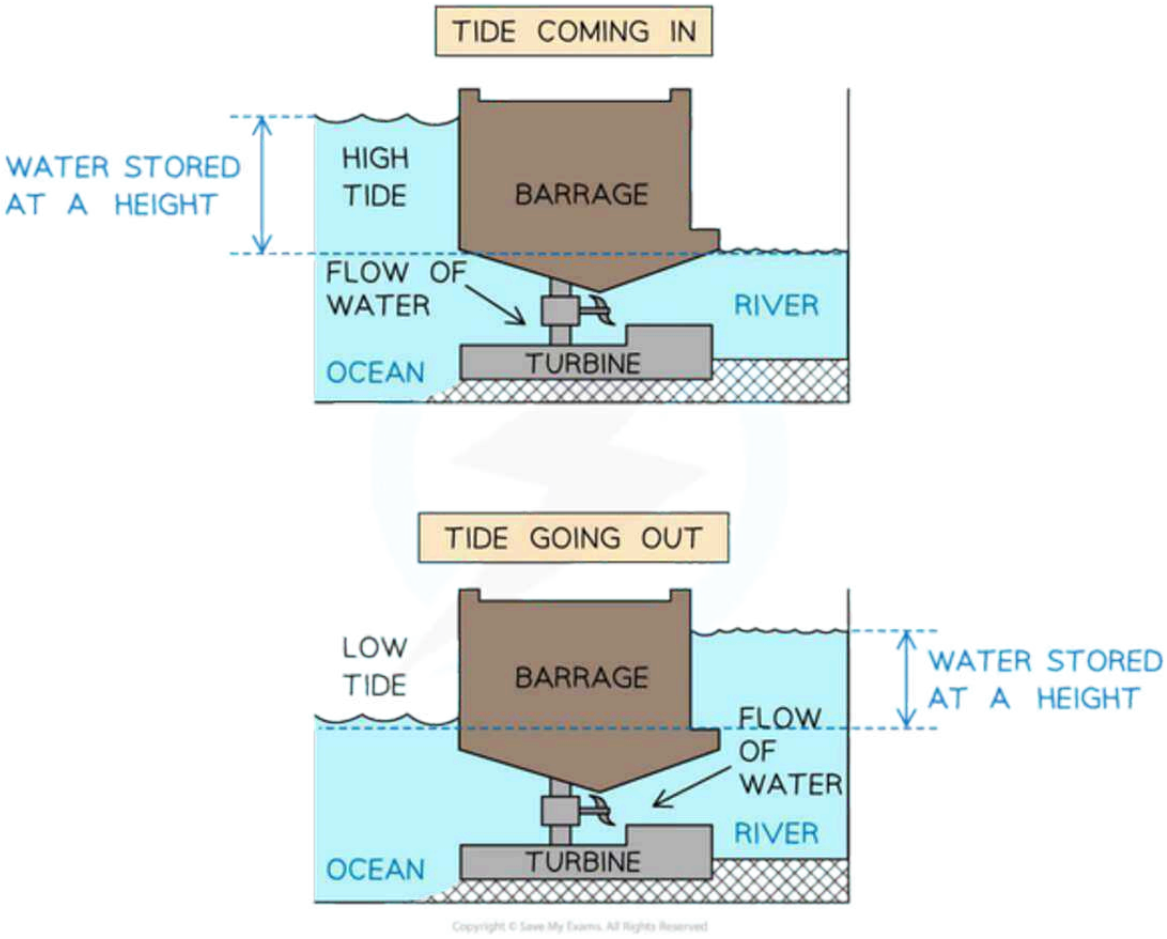


Underwater turbines generate electricity

Turbines using Tidal Power

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Your notes



Tidal Barrage

Advantages

- **No pollution**
- **Reliable** and can produce a large amount of electricity at short notice
- **Renewable** energy resource
- **Small systems** are being developed to provide electricity for small islands

Disadvantages

- **Expensive** to build
- Damages fragile **habitats**
- Very few suitable locations
- The technology is not advanced enough for **large scale** electricity production

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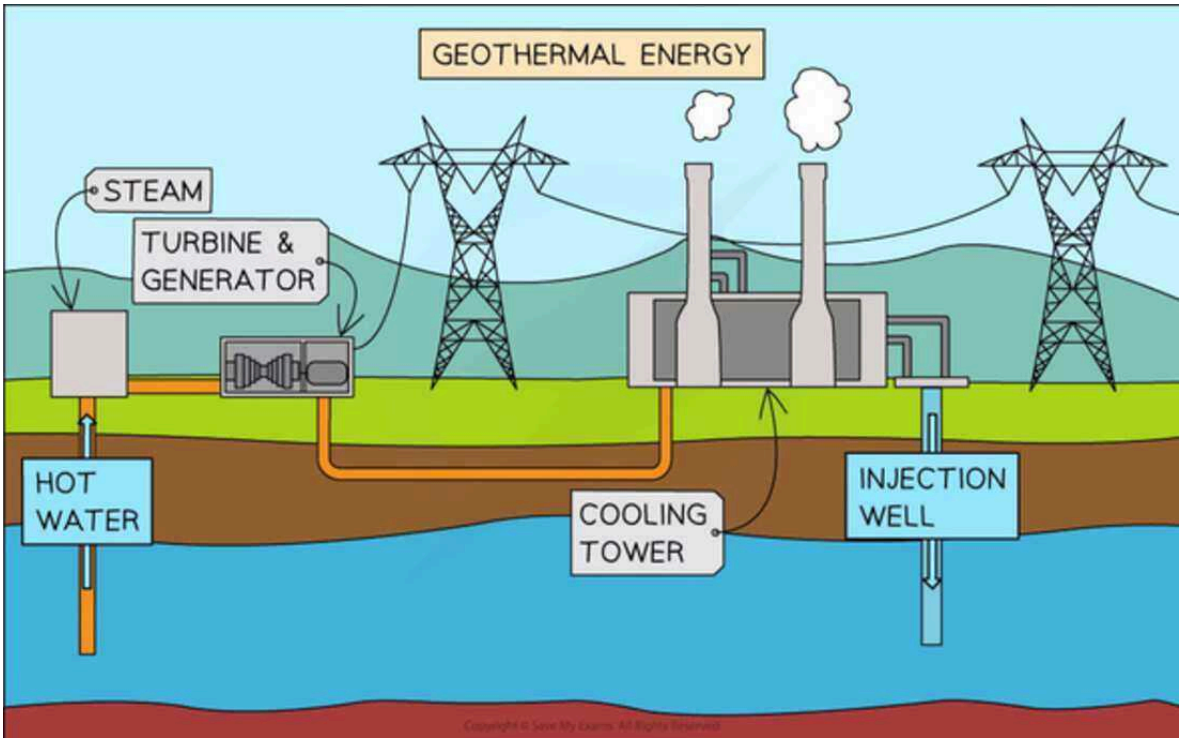
Geothermal Energy

Your notes

Geothermal Energy

- Radioactive elements deep in the Earth release energy as they decay, this **geothermal energy** heats up the rocks, sometimes to a high temperature
- **Water** can be poured into shafts below the Earth's surface which is **heated by the rocks** and returned via another shaft as steam or hot water
- Steam can be used to turn a turbine and **generate electricity**, and hot water can be used to **heat homes**

Power Station using Geothermal Energy



Cold water is heated by the rocks and returned as hot water or steam which can be used to generate electricity

Advantages

- **Renewable** resource
- **Reliable** source of energy
- Geothermal power stations are usually small compared to nuclear or fossil fuel power stations

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Disadvantages

- Few suitable locations on Earth so **small scale** production of electricity
- Can result in the release of greenhouse gases from underground
- Expensive to build



Your notes

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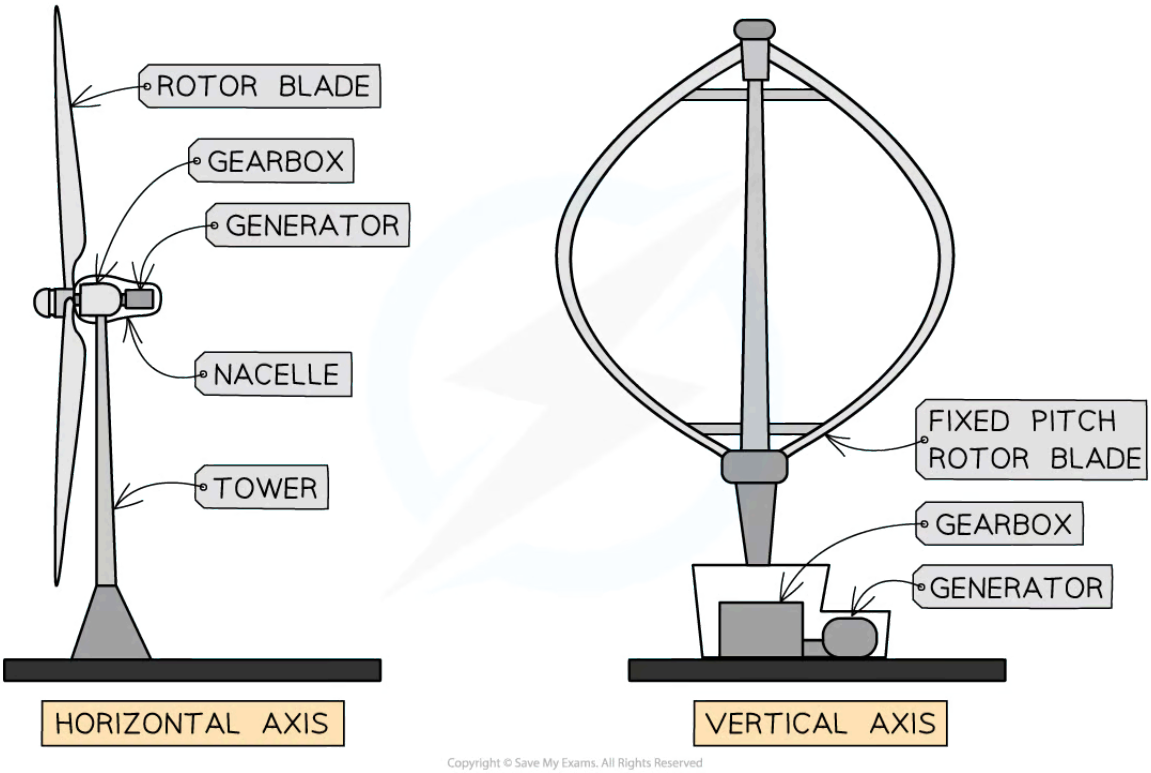
Energy from Wind

Your notes

Wind Power

Wind Electricity Generators

- Energy is harnessed from wind electricity generators from wind turbines
- Wind generators can be principally horizontally or vertically aligned
 - The majority of modern designs use **horizontally** aligned designs



The two main designs of wind generators: horizontal and vertical alignment

- The approximate **efficiency** of wind generators is approximately **30%**
 - Energy is **lost** to aerodynamic limits, losses transferring the electricity to the grid and friction within the system

- **Wind turbines** are regularly placed in coastal areas, with windy conditions to generate electricity
 - A group of wind turbines creates a **wind farm**
 - These are used to power nearby towns and cities

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Your notes

Wind turbines



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Wind farms can be harmful to wildlife, which may mean they shouldn't be built in certain areas

Advantages & Disadvantages of Wind Power

- **Advantages** of using wind-powered generators include:
 - Clean (non-polluting) energy generation (no greenhouse gases / pollution)
 - Freely available

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- Is always sustainable and will never run out

- **Disadvantages** of using wind-powered generators include:
 - Not consistent energy production (only when it is windy)
 - Needs favourable local conditions to be placed in windy locations i.e. on the coast so cannot be in a city
 - Can be visually unappealing
 - Can harm some wildlife (e.g. birds)


Your notes

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Cambridge O Level Physics

Your notes

1.8 Pressure

Contents

- Pressure & Forces
- Pressure in a Liquid

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Pressure & Forces

Your notes

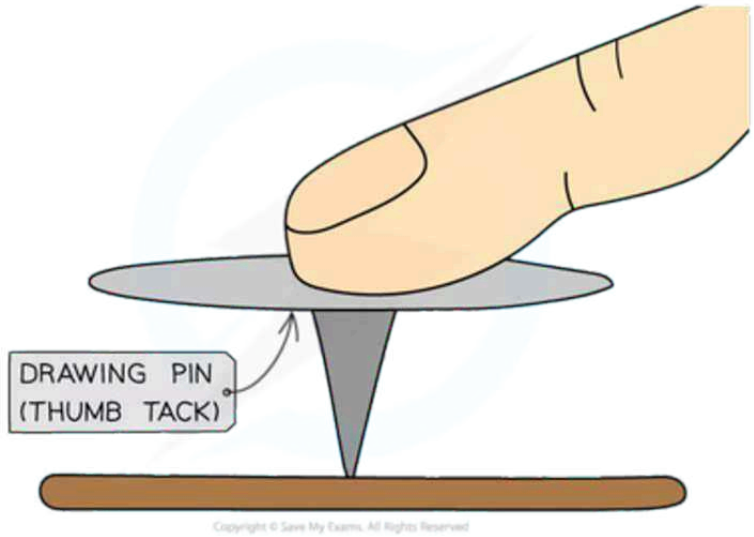
Pressure

- **Pressure** is defined as

The force applied per unit area

- For example, when a drawing pin is pushed downwards:
 - It is pushed into the surface, rather than up towards the finger
 - This is because the sharp point is more **concentrated** (a small area) creating a **larger** pressure

Equal Forces but Inequal Pressures



When you push a drawing pin, it goes into the surface (rather than your finger)

- **Example 1:** Tractors
 - Tractors have **large tyres**
 - This spreads the weight (force) of the tractor over a large area
 - This reduces the pressure which prevents the heavy tractor from sinking into the mud
- **Example 2:** Nails
 - Nails have **sharp pointed ends** with a very small area
 - This concentrates the force, creating a large pressure over a small area
 - This allows the nail to be hammered into a wall
- The pressure at the surface of a fluid can be calculated using the equation:

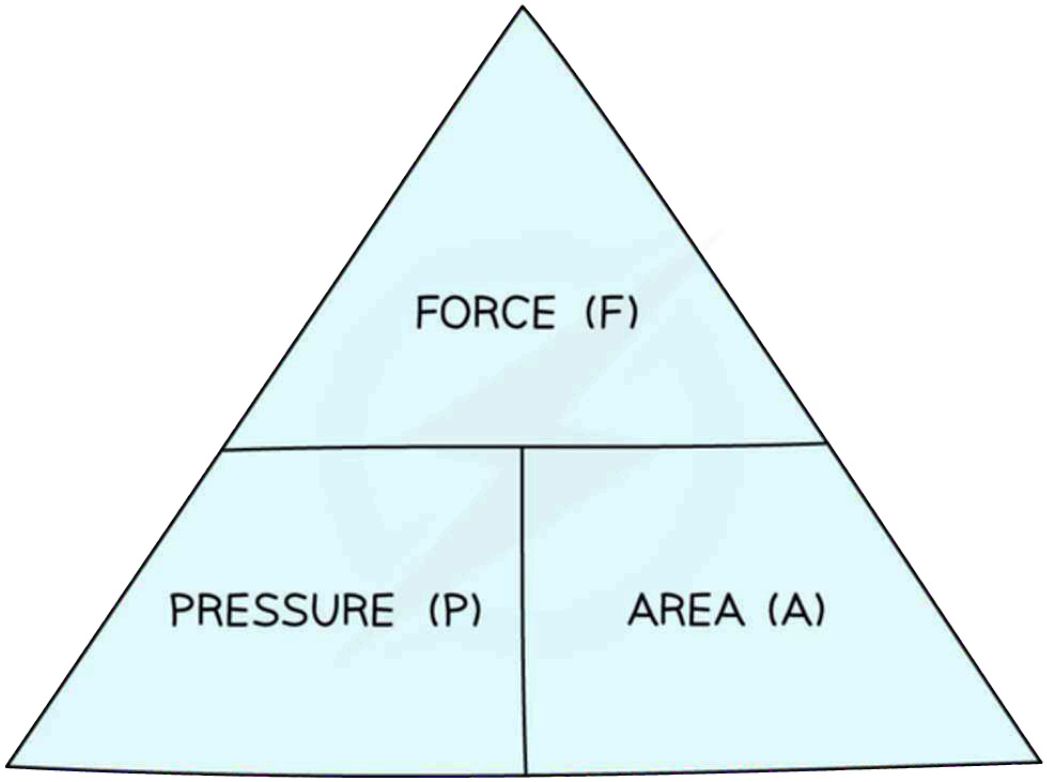
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$$P = \frac{F}{A}$$

Your notes

- Where:
 - P is pressure (Pa)
 - F is force (N)
 - A is area (m^2)
- Pressure is measured in the units **Pascals (Pa)**
- The area should always be the **cross-sectional area** of the object
 - This means the area where the force is at right angles to it
- This equation can be rearranged with the help of a formula triangle:

Formula Triangle for Pressure



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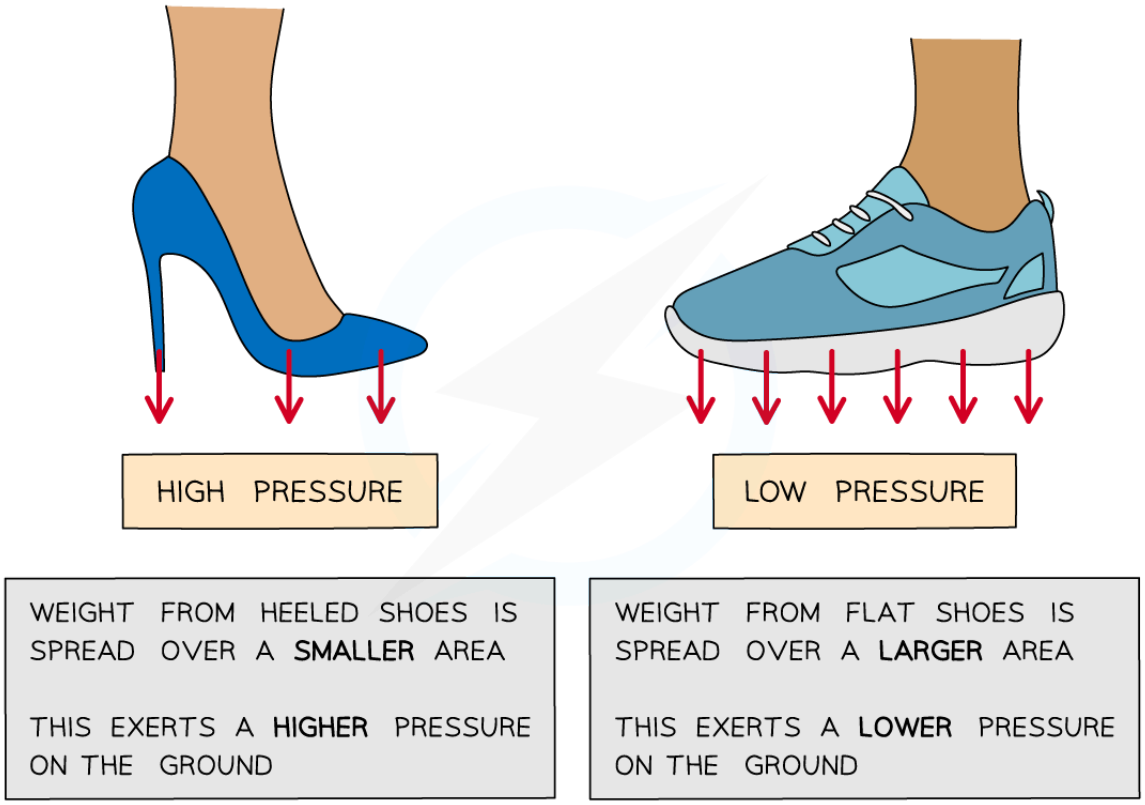
Pressure, force, area formula triangle

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Your notes

- This equation tells us that:
 - If a force is spread over a **large** area it will result in a **small** pressure
 - If it is spread over a **small** area it will result in a **large** pressure

Pressure of High Heels vs Flat Shoes



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High heels produce a higher pressure on the ground because of their smaller area, compared to flat shoes

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Pressure in a Liquid

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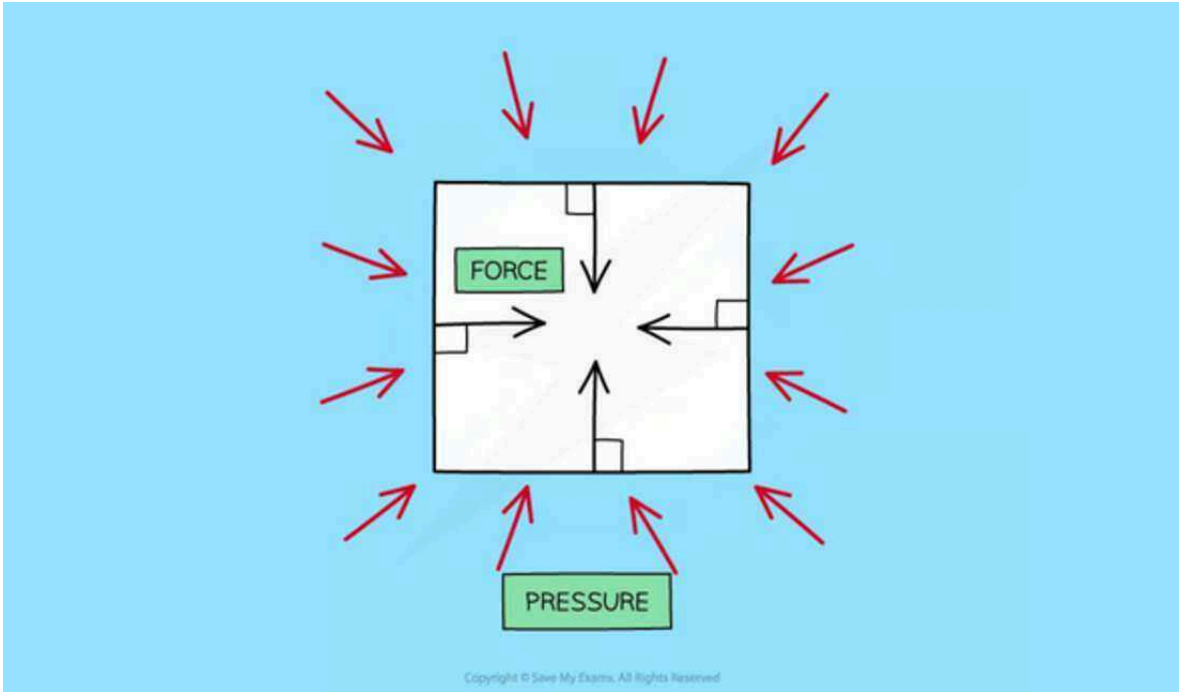
Pressure in Liquids

- A fluid is either a **liquid** or a **gas**

When an object is immersed in a fluid, the fluid will exert pressure, squeezing the object

- This pressure is exerted evenly across the whole surface of the fluid and in **all directions**
- The pressure exerted on objects in fluids creates **forces** against surfaces
- These forces act at **90 degrees** (at right angles) to the surface

Pressure on an Object in a Fluid



The pressure of a fluid on an object creates a force normal (at right angles) to the surface

- The pressure of a fluid on an object will increase with:
 - Depth within the fluid
 - Increased density of the fluid

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Calculating Pressure in Liquids

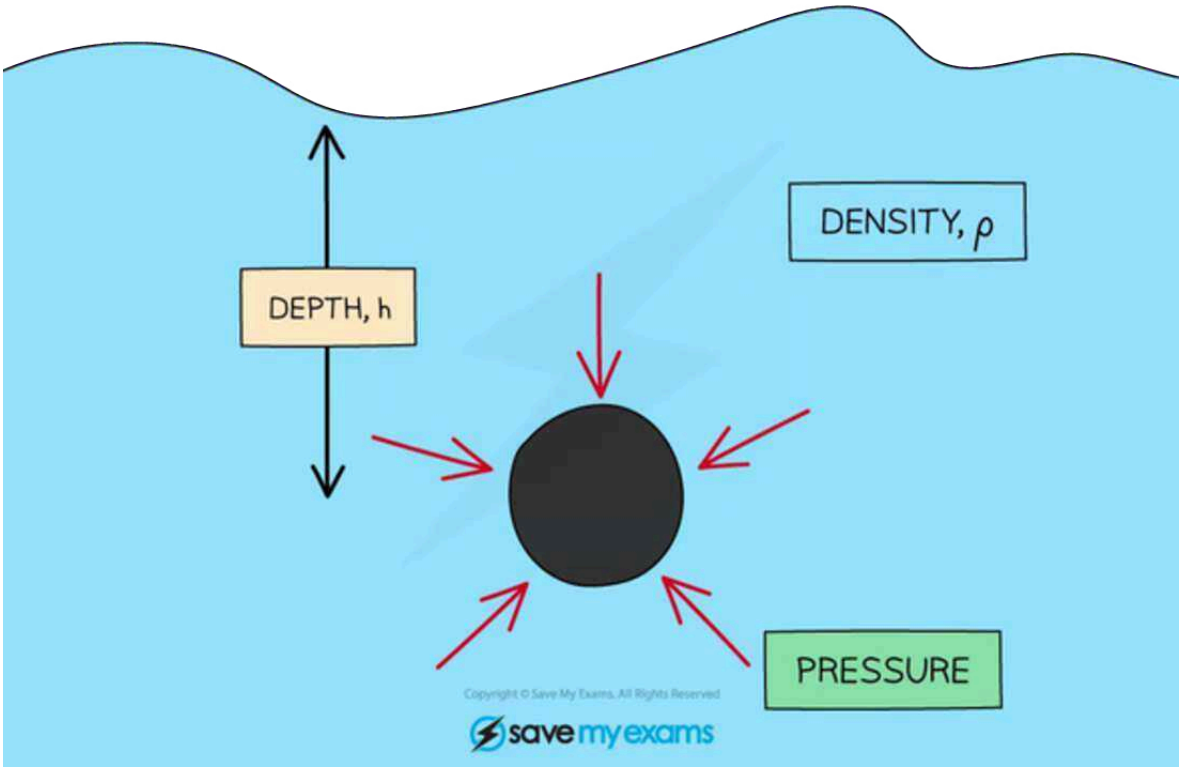
Your notes

- The pressure is more accurately the **difference** in pressure at different depths *h* in a liquid, since the pressure changes with the depth
- The pressure due to a column of liquid can be calculated using the equation

$$\Delta p = \rho g \Delta h$$

- Where:
 - Δp = change in pressure in pascals (Pa)
 - Where 1 Pa = 1 N/m^2
 - ρ = density of the liquid in kilograms per metre cubed (kg/m^3)
 - g = gravitational field strength on Earth in newtons per kilogram (N/kg)
 - Δh = change in height of the column in metres (m)
- The force from the pressure is exerted evenly across the whole surface of an object in a liquid, and in **all** directions

Even Pressure on an Object in a Fluid



The force from the pressure of objects in a liquid is exerted evenly across its whole surface

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Worked example

Calculate the depth of water in a swimming pool where a pressure of 20 kPa is exerted due to the water. The density of water is 1000 kg/m^3 and the gravitational field strength on Earth is 9.8 N/kg.

Answer:

Step 1: List the known quantities, converting any units necessary:

- Pressure due to fluid, Δp = 20 kPa = 20 000 Pa
- Density of water, ρ = 1000 kg/m^3
- Gravitational field strength, g = 9.8 N/kg

Step 2: Rearrange the relevant equation for depth:

- The equation for pressure in a fluid is

$$\Delta \square = \square \square \Delta h$$

- Rearrange for depth, Δh

$$\Delta h = \frac{\Delta \square}{\square \square}$$

Step 3: Substitute the known quantities:

- Depth is

$$\Delta h = \frac{20\ 000}{1000 \times 9.8}$$

$$\Delta h = 2.0408 \text{ m}$$

- Give the answer to 2 significant figures (like the values given in the question)

$$\Delta h = 2.0 \text{ m}$$

Exam Tip

This pressure equation will be given on your formula sheet, however, make sure you are comfortable with rearranging it for the variable required in the question!

Your notes

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Cambridge O Level Physics

Your notes

2.1 Kinetic Particle Model of Matter

Contents

- States of Matter
- Particle Model
- Temperature & Pressure
- Gases & Absolute Temperature

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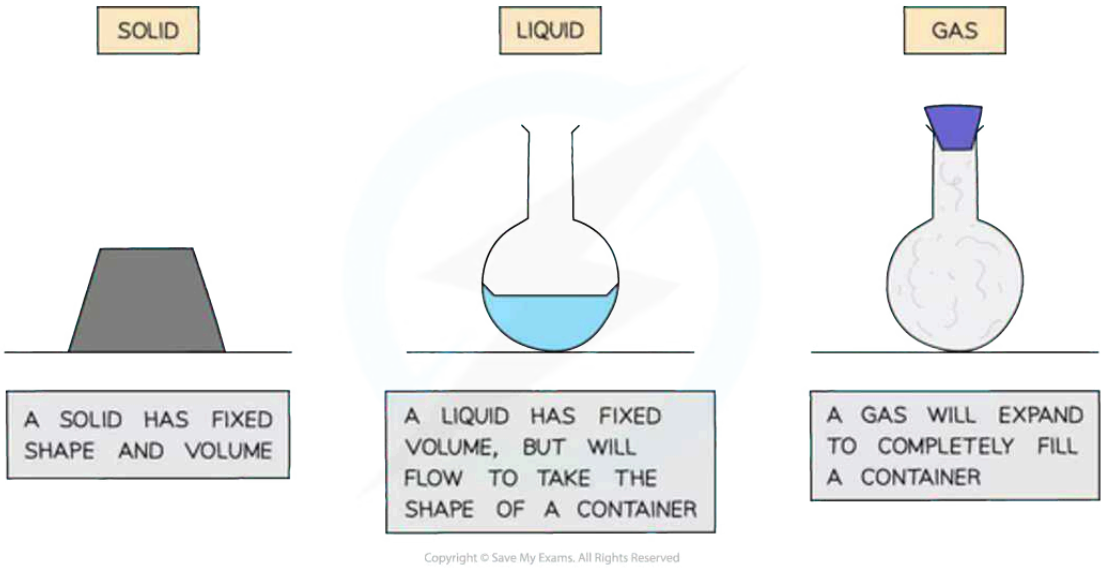
States of Matter

Your notes

Properties of Solids, Liquids & Gases

- The three states of matter are **solids**, **liquids** and **gases**

A solid, a liquid and a gas



The three states of matter in terms of shape and volume

Solids

- Solids have a definite **shape** and a definite **volume**
 - Solids cannot flow and are **incompressible**

Liquids

- Liquids have no definite shape but do have a definite **volume**
 - Liquids are able to flow to take the shape of a container but they are **incompressible**

Gases

- Gases have **no** definite shape and no fixed volume
 - Gases can flow to take the shape of their container and are highly **compressible**

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Changes of State

Your notes

When a substance changes state, the number of molecules in that substance doesn't change and so neither does its mass

- The only thing that changes is its **energy**
- Changes of state are physical changes and so they are **reversible**

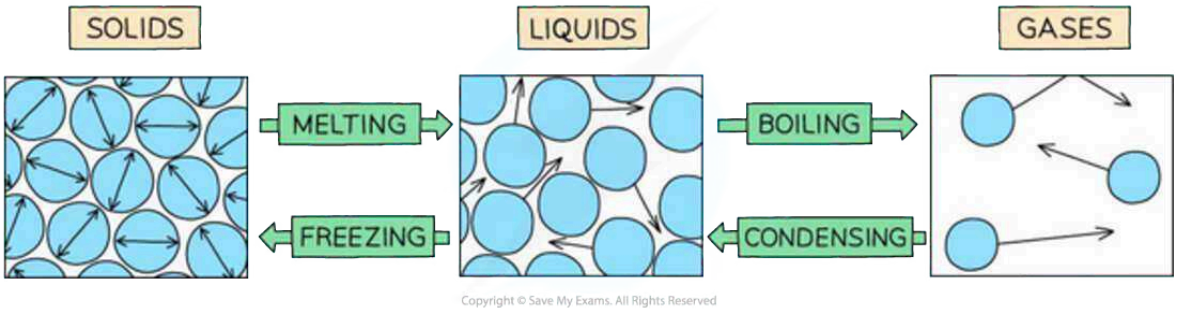
Melting & Freezing

- Melting occurs when a solid turns into a liquid (e.g. ice to water)
- Freezing occurs when a liquid turns into a solid

Boiling & Condensing

- Boiling occurs when a liquid turns into a gas
 - This is also called evaporating
- Condensing occurs when a gas turns into a liquid

Diagram of Changes of State



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Melting and freezing are changes between solid and liquid states, boiling and condensing are changes between liquid and gas states

Exam Tip

It is very useful to think about water when learning the changes of state, because we are all used to the idea that solid water (ice) melts to become liquid water (water!) and boils to become gaseous water (water vapour).

However do remember that **all** substances undergo the same changes between the three states, but at different temperatures. So while water will help you to remember the names, don't refer to water in your answers unless it has been specified.

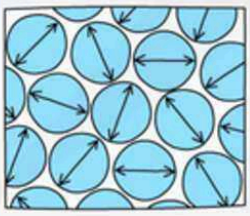
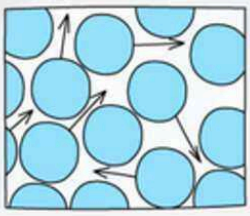
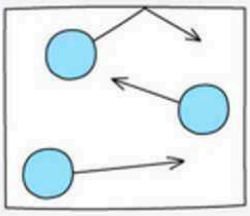
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Particle Model

Your notes

Arrangement & Motion of Particles

- In a **solid**:
 - The molecules are very **close** together and arranged in a **regular** pattern
 - The molecules **vibrate** about fixed positions
- In a **liquid**:
 - The molecules are still **close** together (no gaps) but are no longer arranged in a regular pattern
 - The molecules are able to **slide past each other**
- In a **gas**:
 - The molecules are **widely separated** - about 10 times further apart in each direction
 - The molecules move about **randomly at high speeds**

State	Solid	Liquid	Gas
Density	High	Medium	Low
Arrangement of particles	Regular pattern	Randomly arranged	Randomly arranged
Movement of particles	Vibrate around a fixed position	Move around each other	Move quickly in all directions
Energy of particles	Low energy	Greater energy	Highest energy
2D diagram			

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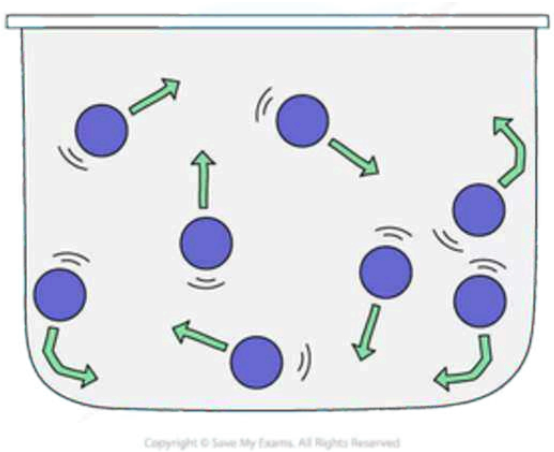
Temperature & Pressure

Your notes

Temperature & Energy of Particles

- Molecules in a gas move around in constant **random** motion at high speeds
- Random motion means that molecules
 - Travel in no specific direction
 - Undergo sudden changes in direction if they collide with either the walls of the container, or with other molecules

Random Motion of Gas Molecules



Gas molecules in a container move around randomly at high speeds

- The motion of molecules in a gas depends on the **temperature** of the gas
- More specifically, the **temperature** of a gas is related to the **average kinetic energy** of the molecules
 - The **hotter** the gas, the **higher** the average kinetic energy
 - The **cooler** the gas, the **lower** the average kinetic energy
- Since the kinetic energy is related to speed, the **speed of the molecules** also changes with temperature (as long as the volume of the container is constant)
 - The **hotter** the gas, the **faster** the gas molecules move
 - The **cooler** the gas, the **slower** the gas molecules move

Absolute Zero

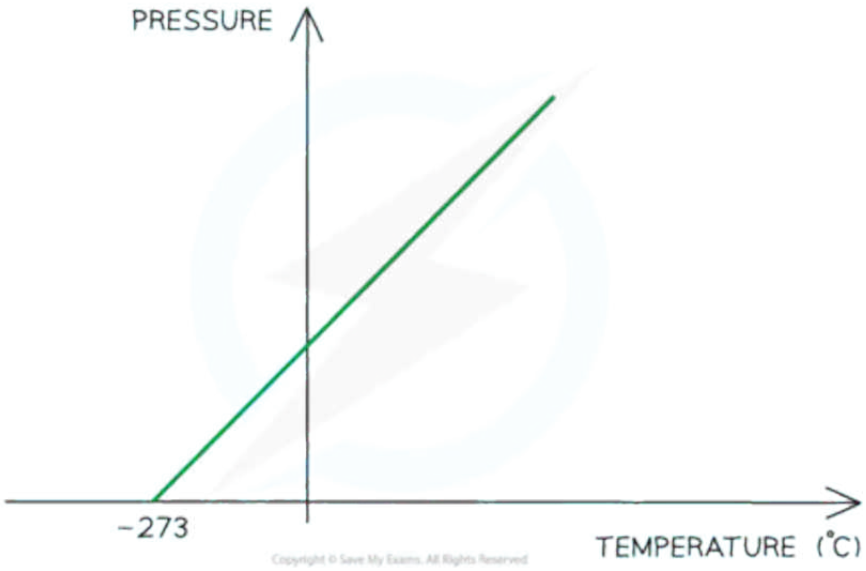
- In 1848, the physicist Lord Kelvin recognised that there must be a temperature at which the particles in a gas must **no longer be moving**, or **exerting pressure** on their surroundings
- This temperature is called **absolute zero** and is equal to –273 °C
- Absolute zero is defined as:

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The temperature at which the molecules in a substance have zero kinetic energy

- This means for a system at absolute zero, it is not possible to remove any more energy from it
- Even in space, the temperature is roughly 2.7°C above absolute zero

Where does absolute zero come from?



At absolute zero (-273°C) particles will have no net movement. It is therefore not possible to have a lower temperature than this

Your notes

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Motion of Particles in a Gas

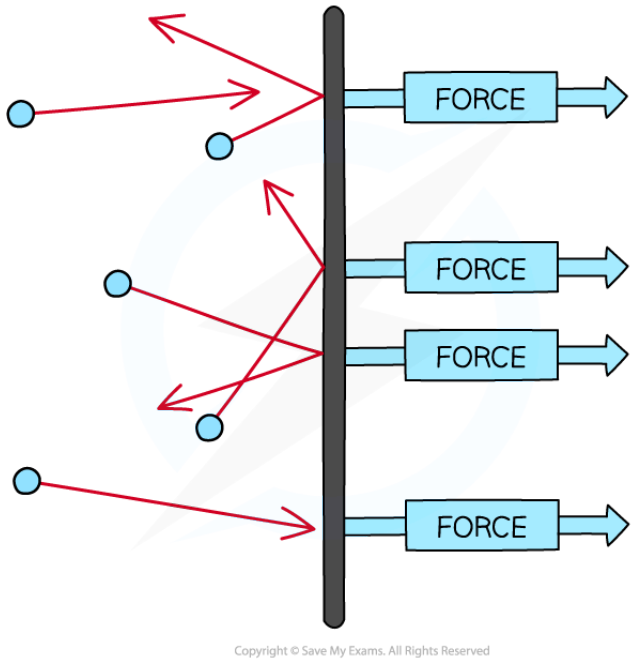
Your notes

- A feature of gases is that they fill the space of any container that they occupy
- As the gas particles move about randomly they collide with the walls of the container and exert a **pressure**
- These collisions produce a **net force** at right angles to the wall of the container (or any surface)
- This pressure is defined as the **force per unit area**

$$P = \frac{F}{A}$$

- Where:
 - P = pressure exerted by the gas (Pa)
 - F = force exerted by the gas (N)
 - A = area the force acts over (m^2)
- This equation means that
 - The **higher** the gas pressure, the **more frequently** the particles collide with the container walls and the **greater** the **force** exerted per unit area
 - The **lower** the gas pressure, the **less frequently** the particles collide with the container walls and the **smaller** the **force** exerted per unit area

Pressure & Force in a Gas



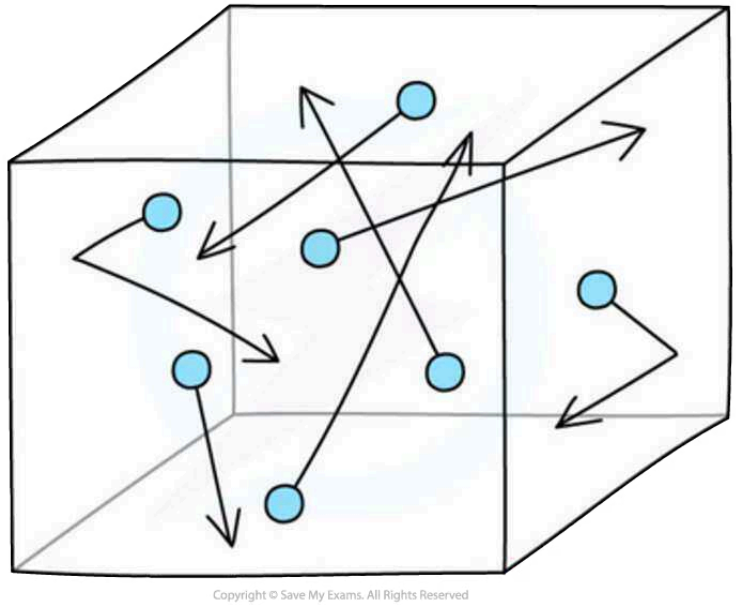
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Gas molecules bouncing off the walls of a container

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- The **pressure** of a gas also depends on the **temperature** of the gas
 - This is because particles move with more energy as their temperature increases
 - As the temperature of the gas decreases, the pressure on the container also decreases

Gas Molecules in a Container



Gas molecules hit the sides of the container and exert a force, which creates pressure

Exam Tip

You can experience the force exerted by a gas yourself by closing your mouth and forcing air into your cheeks

The strain you feel on your cheeks is due to the increased pressure of the gas particles pushing at right angles to your cheeks

Your notes

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Gases & Absolute Temperature

Your notes

Absolute Temperature

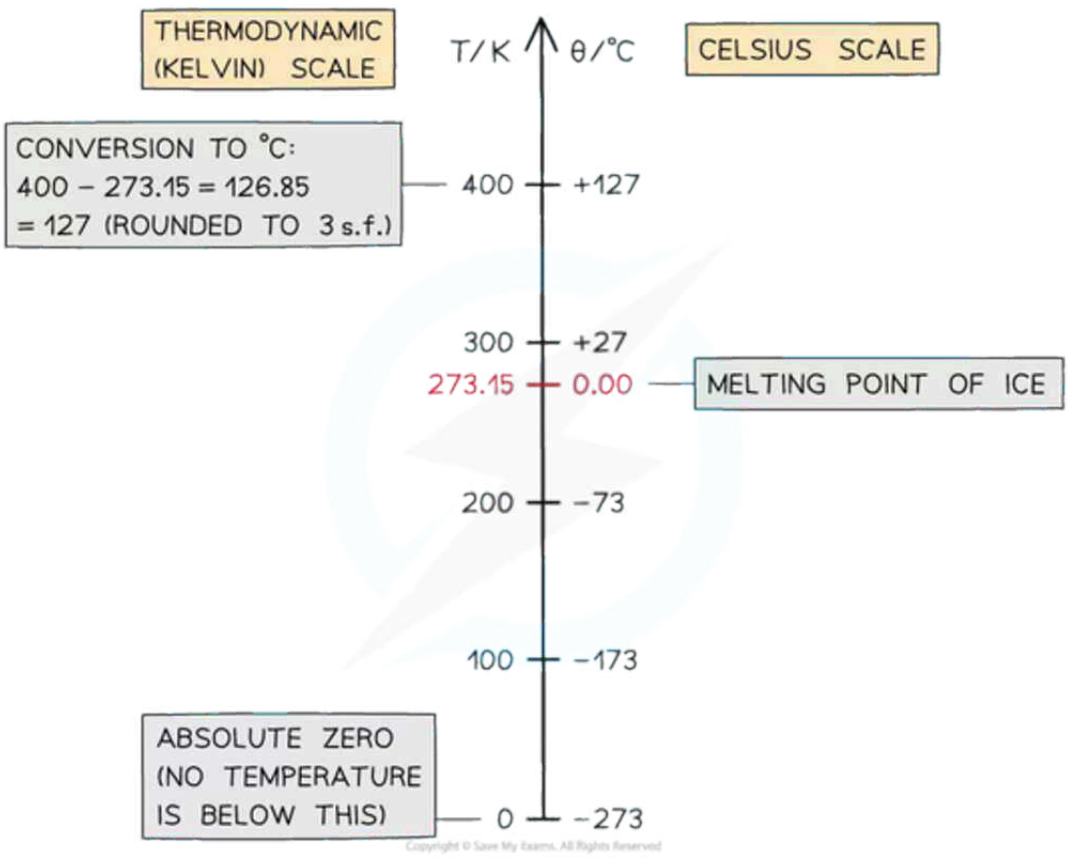
- The **Kelvin temperature scale** begins at **absolute zero**
 - Absolute zero, or 0 K, is equal to –273 °C
 - An increase of 1 K is the same change as an increase of 1 °C
- It is not possible to have a temperature **lower** than 0 K
- This means a temperature in Kelvin will **never** have a negative value
- To convert between temperatures θ in the Celsius scale, and T in the Kelvin scale, use the following conversion:

$$\theta / ^{\circ}C = T / K - 273$$

$$T / K = \theta / ^{\circ}C + 273$$

Kelvin Scale and Celsius Scale

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Conversion chart relating the temperature on the Kelvin and Celsius scales

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Worked example

Convert the following values between the Kelvin (absolute) and Celsius scales of temperature.

(a) 0 K = ... °C

(b) 0 °C = ... K

(c) 20 °C = ... K

Answer:

(a)

Step 1: Choose whether to add or subtract 273 to the value

- The question is in Kelvin therefore subtract 273 to convert to Celsius

Step 2: Do the calculation

$$0 - 273 = -273\ °C$$

Step 3: Write the answer with units

- 0 K = **-273 °C**

(b)

Step 1: Choose whether to add or subtract 273 to the value

- The question is in Celsius therefore add 273 to convert to kelvin

Step 2: Do the calculation

$$0 + 273 = 273\ K$$

Step 3: Write the answer with units

- 0 °C = **273 K**

Part (c)

Step 1: Choose whether to add or subtract 273 to the value

- The question is in Celsius therefore add 273 to convert to kelvin

Step 2: Do the calculation

$$20 + 273 = 293\ K$$

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Step 3: Write the answer with units

- 20 °C = **293 K**



Your notes

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The Gas Laws

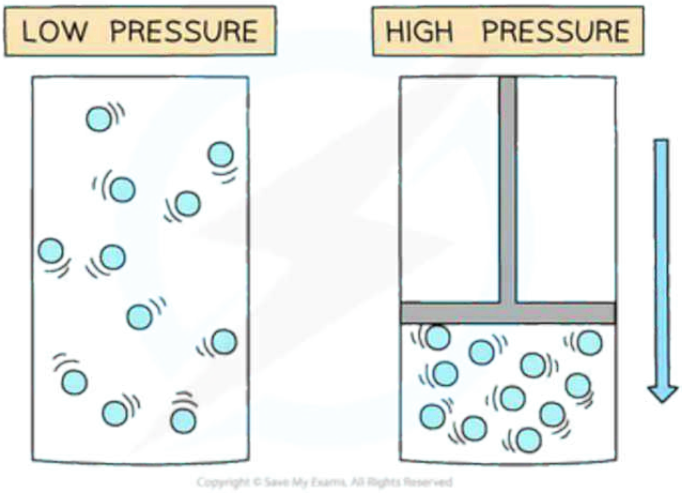
Your notes

- The gas laws describe the relationships between the **pressure**, **volume** and **temperature** of a gas

Pressure & Volume at Constant Temperature

- If the temperature of a gas remains **constant**, the pressure of the gas changes when it is:
 - **Compressed** – decreasing the volume causes pressure to **increase**
 - **Expanded** – increasing the volume causes pressure to **decrease**

Decreasing Volume Increases Pressure



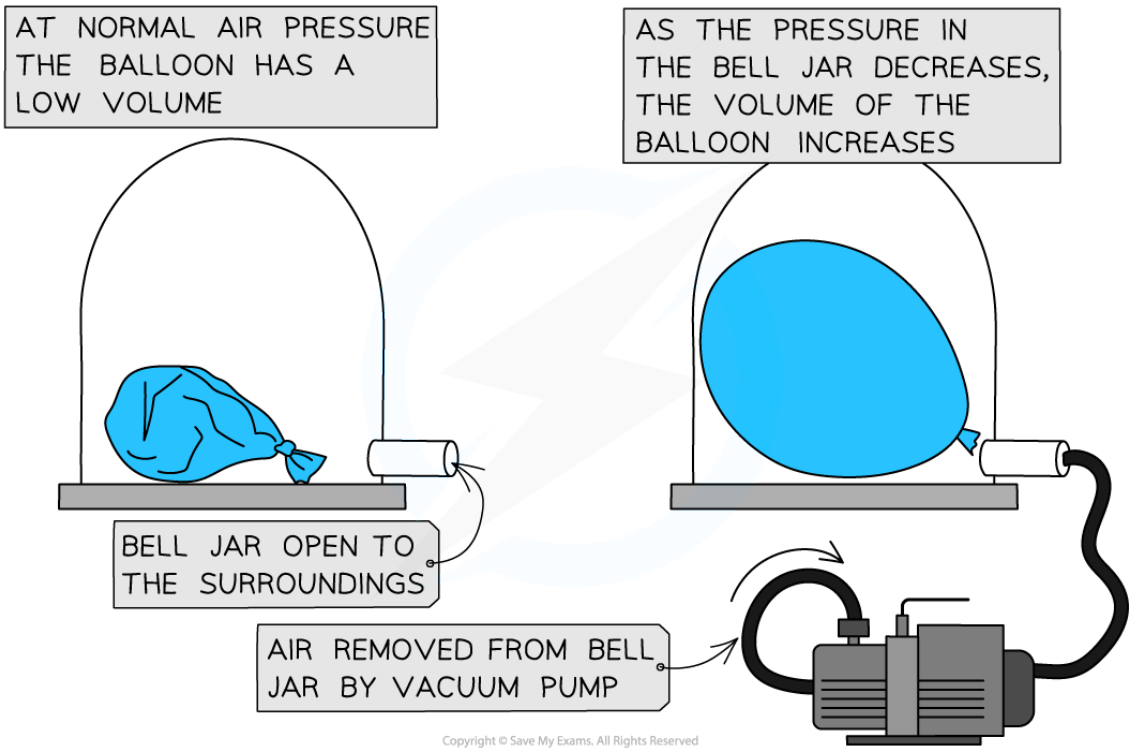
Pressure increases when a gas is compressed

- Similarly, a change in pressure can cause a change in volume
- A **vacuum pump** can be used to remove the air from a sealed container
- The diagram below shows the change in volume of a tied up balloon when the pressure of the air around it decreases:

Decreasing Pressure Increases Volume

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Your notes



Decreasing pressure from the air surrounding the balloon on the right allows the pressure from the air particles within to increase the volume of the balloon

- When a gas is compressed, the molecules will hit the walls of the container **more frequently**
 - This creates a larger overall **net force** on the walls which increases the **pressure**

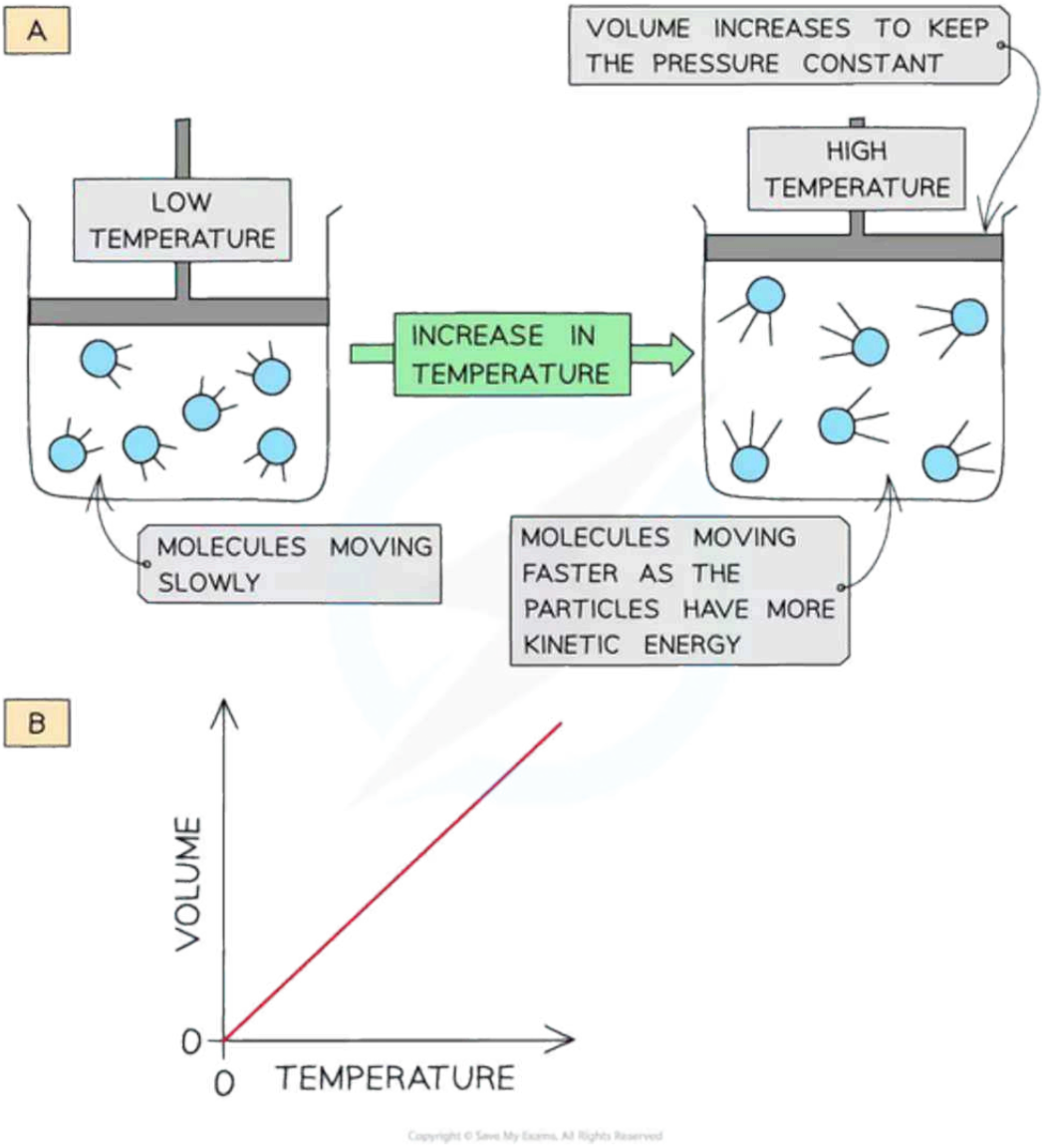
Volume & Temperature at Constant Pressure

- If a gas is placed in a container which allows it to expand and compress (e.g. a piston) then its pressure can be kept **constant**
- As a result, changes in temperature at constant pressure will affect the volume only
- If the pressure of a gas remains **constant**, the volume of the gas changes when:
 - The gas gets **hotter** – increasing the temperature causes the gas to **expand** (volume increases)
 - The gas gets **cooler** – decreasing the temperature causes the gas to **compress** (volume decreases)

Relationship between Volume & Temperature

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Your notes



At constant pressure, an increase in the temperature of the gas causes it to expand

- In the diagram above:
 - Diagram A shows molecules expanding into a greater volume as the temperature increases
 - Diagram B shows that the volume of the gas is directly proportional to the temperature

Pressure & Temperature at Constant Volume

- If the temperature of a gas is increased, the particles move faster and gain kinetic energy

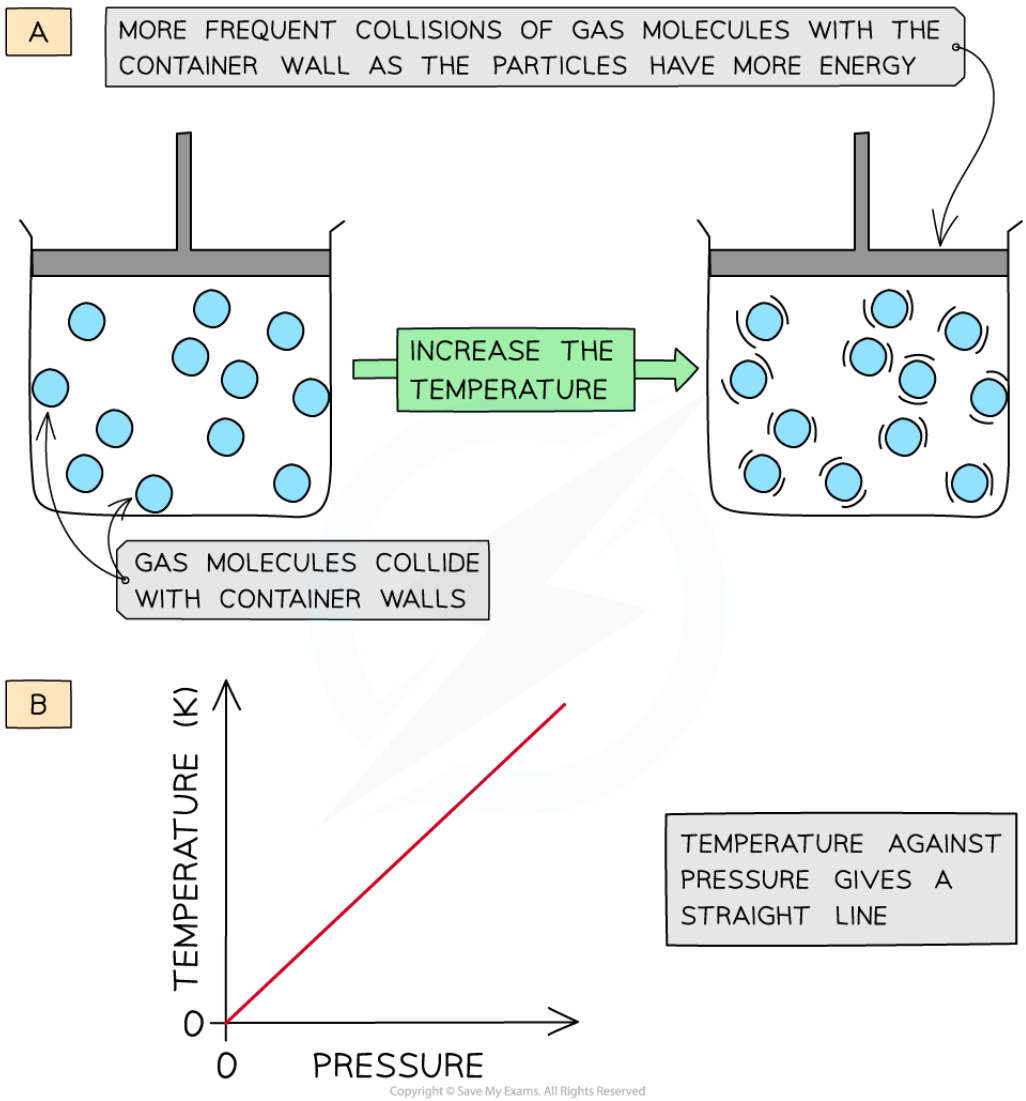
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- As a result, they will collide more often leading to an **increase** in pressure

- If the volume of a gas remains **constant**, the pressure of the gas changes when:
 - The gas gets **hotter** – increasing the temperature causes the pressure to increase
 - The gas gets **cooler** – decreasing the temperature causes the pressure to decrease

Your notes

Relationship between Pressure & Temperature



At constant volume, an increase in the temperature of the gas increases the pressure due to more collisions on the container walls

- In the diagram above:

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- Diagram A shows molecules in the same volume colliding with the walls of the container more often as the temperature increases
- Diagram B shows that the temperature of a gas is directly proportional to the gas pressure


Your notes

Exam Tip

You are required to be able to describe the links between pressure & volume and pressure & temperature **qualitatively**. This means that the correct use of terms such as 'collision', 'kinetic energy' and 'frequency', will be really important.

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Boyle's Law

Your notes

- For a fixed mass of a gas held at a constant temperature:

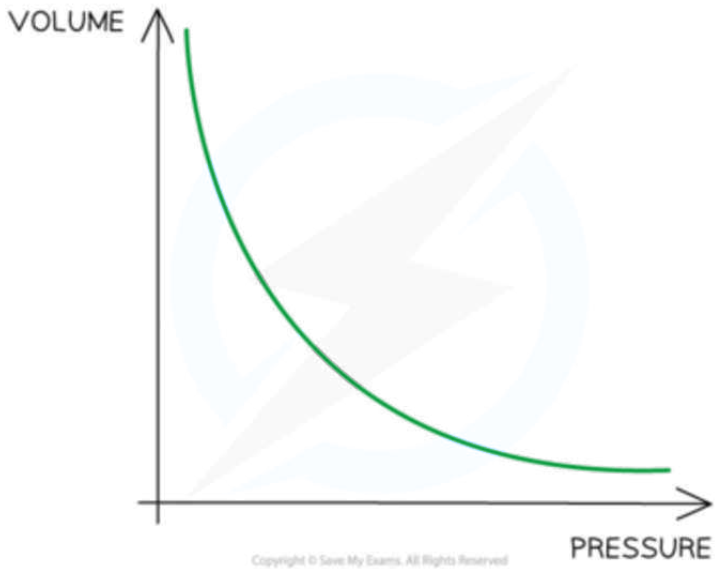
$$pV = \text{constant}$$

- Where:
 - p = pressure in pascals (Pa)
 - V = volume in metres cubed (m^3)
- This means that the pressure and volume are inversely proportional to each other
 - When the volume **decreases** (compression), the pressure **increases**
 - When the volume **increases** (expansion), the pressure **decreases**
- This relationship is known as **Boyle's Law** and can also be written as:

$$P \propto \frac{1}{V}$$

- This means the pressure is **inversely proportional** to the volume of a gas

Graph Showing Boyle's Law



Boyle's Law shows that pressure is inversely proportional to volume

- The relationship between the pressure and volume for a fixed mass of gas at constant temperature can also be written as:

$$P_1 V_1 = P_2 V_2$$

- Where:

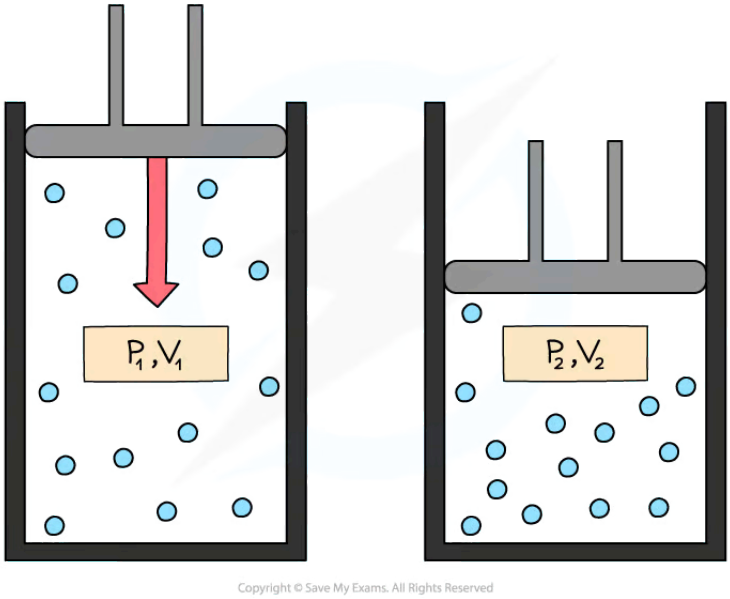
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- P_1 = initial pressure (Pa)
- P_2 = final pressure (Pa)
- V_1 = initial volume (m^3)
- V_2 = final volume (m^3)

- Notice that volume and pressure are measured in m^3 and Pa respectively
- In calculations, if units are given in cm^3 or MPa this is a rare case where calculations can be done using the original units **as long as answers are reported in the same, original units**

Your notes

Calculating Changes in Pressure & Volume



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Initial pressure and volume, P_1 and V1, and final pressure and volume, P_2 and V_2

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Worked example

A gas occupies a volume of 0.70 m^3 at a pressure of 200 Pa.

Calculate the pressure exerted by the gas if it is compressed to a volume of 0.15 m^3.

Assume that the temperature and mass of the gas stay the same.

Answer:

Step 1: List the known quantities

- Initial volume, $V_1 = 0.70\ m^3$
- Initial pressure, $P_1 = 200$ Pa
- Final volume, $V_2 = 0.15\ m^3$

Step 2: Write down the relevant equation

$$P_1 V_1 = P_2 V_2$$

Step 3: Rearrange for the final pressure P_2

$$P_2 = \frac{P_1 V_1}{V_2}$$

Step 4: Substitute the values into the equation

$$P_2 = \frac{200 \times 0.70}{0.15} = 930 \text{ Pa}$$

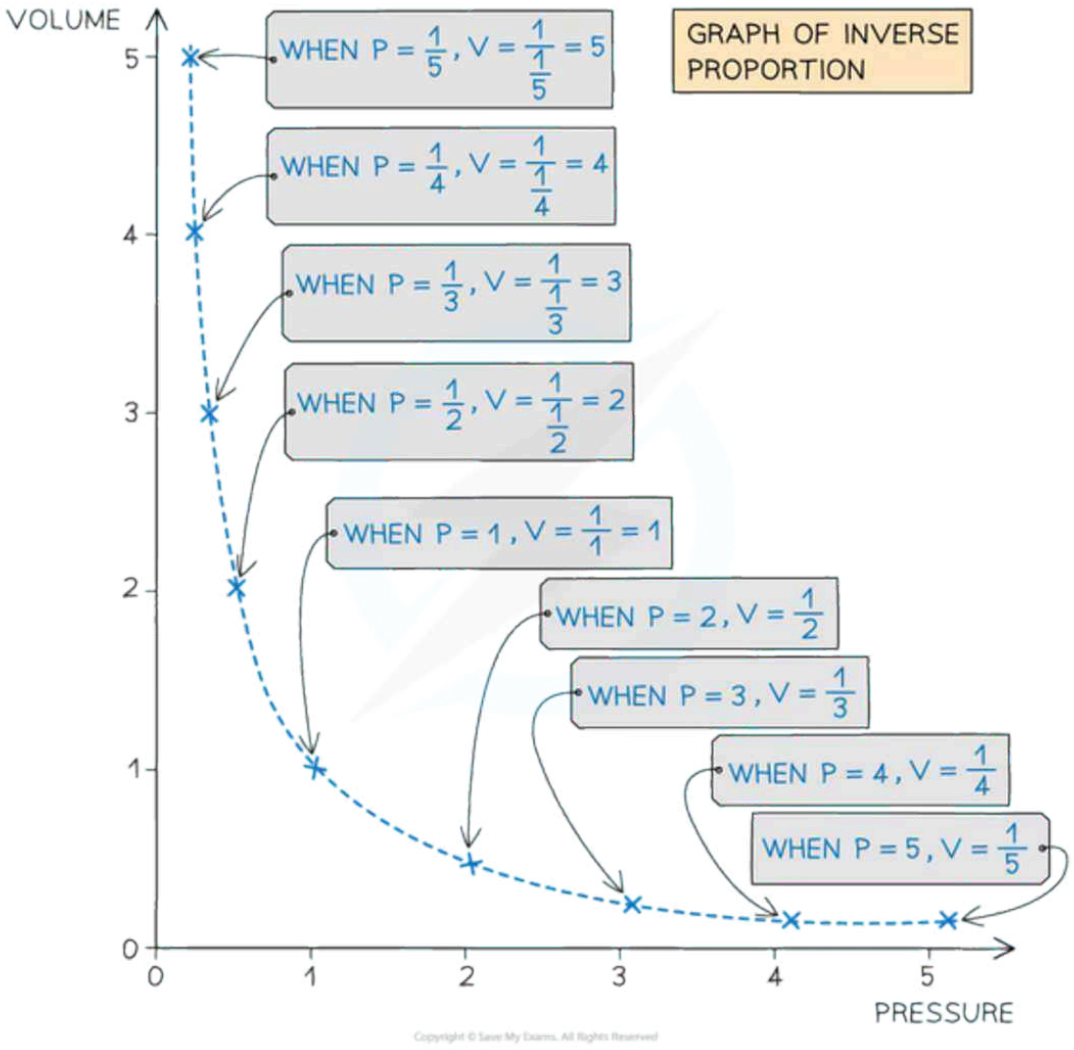
Your notes

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Exam Tip

It is an easy mistake to make to think that an inversely proportional graph will be a straight line sloping downwards. After all, a directly proportional graph is a straight line (through the origin) which slopes upwards!

The curve above which 'tends towards zero' (meaning the curve gets closer and closer but never touches the axis, or zero is an inversely proportional curve, as the graph below shows.



Your notes

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Cambridge O Level Physics

Your notes

2.2 Thermal Properties & Temperature

Contents

- Thermal Expansion
- Specific Heat Capacity
- Investigating Specific Heat Capacity
- Melting, Boiling & Evaporation
- Evaporation

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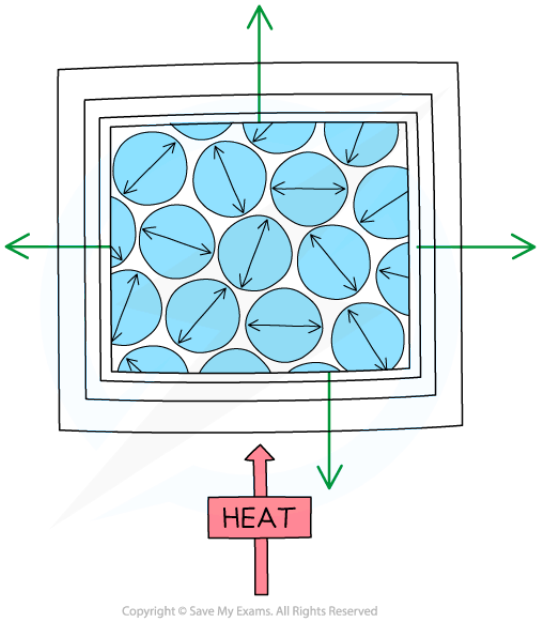
Thermal Expansion

Your notes

Thermal Expansion

- When a material is heated:
 - Its temperature increases
 - Its overall volume increases (it **expands**)
 - Its density decreases
- This expansion happens because:
 - The molecules start to move around (or vibrate) faster as they gain kinetic energy
 - This causes them to collide with each other more often and push each other apart

Thermal Expansion in a Solid



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When a solid is heated, the molecules vibrate more, pushing each other apart

- Thermal expansion occurs in solids, liquids and gases
- When temperature is increased (at constant pressure):
 - Solids will tend to expand the least
 - Gases expand the most
 - Liquids fall in between the two

Table Comparing Thermal Expansion of Solids, Liquids and Gases

State	Magnitude of Expansion	Explanation

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Solid	Expands slightly	The low energy molecules cannot overcome the intermolecular forces of attraction holding them together
Liquid	Expands more than solids	The molecules have enough energy to partially overcome the intermolecular forces of attraction holding them together
Gas	Expand significantly	The high energy molecules have enough energy to completely overcome the intermolecular forces of attraction holding them together


Your notes

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Uses & Consequences of Thermal Expansion

Your notes

- The thermal expansion of materials can have some **useful applications** as well as some **undesirable consequences**

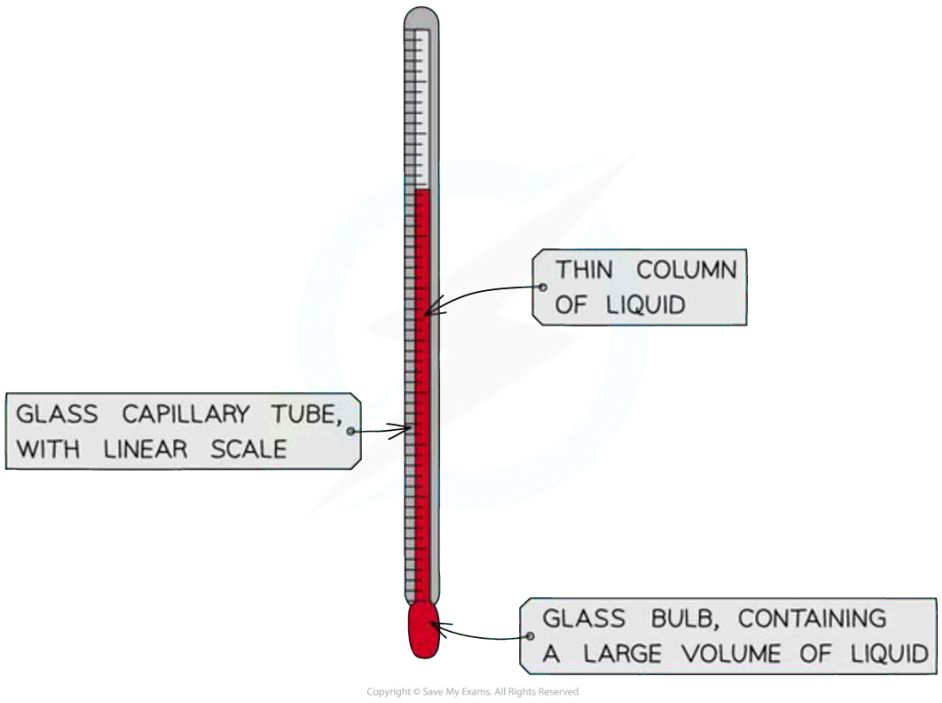
Applications of Thermal Expansion

- Useful applications of thermal expansion include:
 - Liquid-in-glass thermometers
 - Temperature-activated switches

Liquid-in-glass thermometer

- A liquid-in-glass thermometer relies on the expansion of liquids to measure temperature
- It consists of a thin glass capillary tube containing a liquid that expands with temperature
 - At one end of the tube is a glass bulb, containing a large volume of the liquid which expands into the narrow tube when heated
 - A scale along the side of the tube allows the temperature to be measured based on the length of liquid within the tube

Liquid-in-glass thermometer



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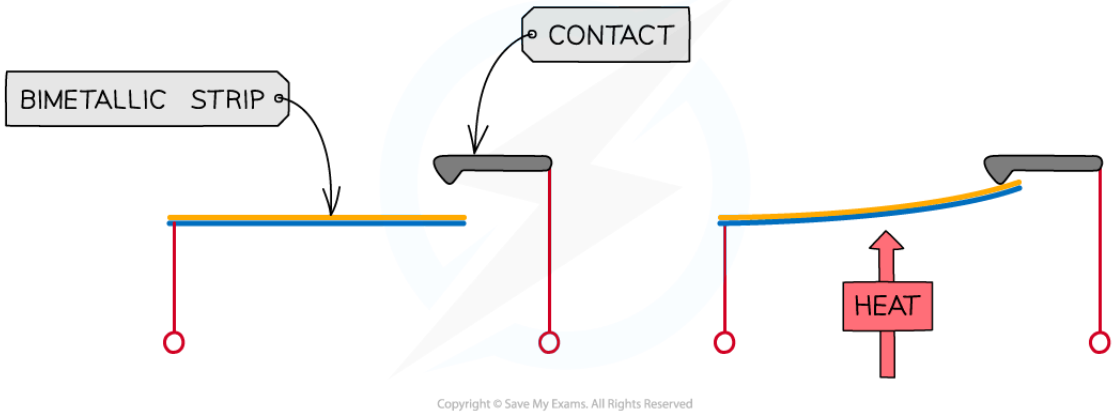
As the bulb is heated, the liquid expands and moves along the capillary tube

Temperature-activated switches

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- Temperature-activated switches utilise a **bimetallic** (made from two types of metal) strip
- It consists of two metals that expand at different rates and bends by a predictable amount at a given temperature

Your notes



The bimetallic strip will bend upwards when heated, closing the circuit

Consequences of Thermal Expansion

- The expansion of solid materials can cause them to buckle if they get too hot
- This could include:
 - Metal railway tracks
 - Road surfaces
 - Bridges
- Objects that are prone to buckling in this way have gaps built in to creates space for the expansion to happen without causing damage

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Worked example

The wooden wheels of horse-drawn carriages can be strengthened by putting a tight ring of iron around them.

Which of the following actions would make it easier to fit the iron ring over the wooden wheel whilst ensuring a tight fit?

A Heating the iron ring

B Heating the wooden wheel

C Cooling the iron ring

D Cooling the wooden wheel

ANSWER: A

- When metals are heated, they expand
- So, heating the iron ring will cause it to expand, hence increasing its diameter
- The expanded iron ring will fit (just) over the wooden wheel
- When the iron ring cools, it will contract, reducing its diameter once again, and ensuring a tight fit around the wooden wheel

Exam Tip

Remember that it is **the material that expands, not the molecules**. This trips up many students, losing marks.

As heat is added:

1. The increase in temperature...
2. Leads to an increase in kinetic energy, so that...
3. Molecules and atoms move more quickly...
4. And move apart
 - This separation of the molecules makes the substance bigger!

Your notes

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Specific Heat Capacity

Your notes

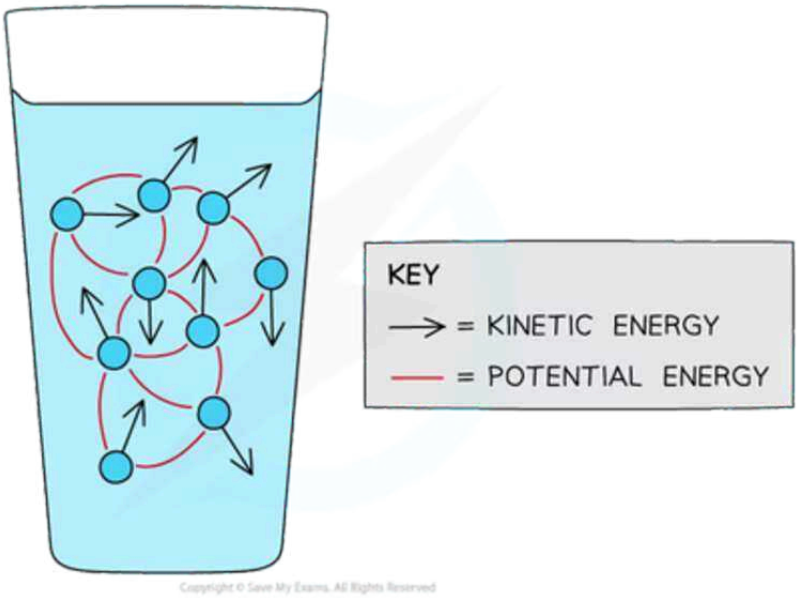
Internal Energy

- A rise in the temperature of an object increases its **internal energy**
 - This can be thought of as due to an increase in the average speed of the particles
 - Increasing speed increases kinetic energy

- Internal energy is defined as:

 The total energy stored inside a system by the particles that make up the system due to their motion and positions

 - **Motion** of the particles affects their **kinetic energy**
 - **Positions** of the particles relative to each other affects their **potential energy**
- Together, these two make up the **internal energy** of the system



Substances have internal energy due to the motion of the particles and their positions relative to each other

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Average Kinetic Energy


Your notes

- Heating a system will change the energy stored in a system by **increasing the kinetic energy** of its particles
 - The Kelvin **temperature** of the gas is related to the average **kinetic energy** of the molecules
- This increase in kinetic energy (and therefore energy stored in the system) can:
 - Cause the **temperature** of the system to increase
 - Or, produce a **change of state** (solid to liquid or liquid to gas)
- The internal energy of a gas is the sum of the kinetic energy of all the molecules
- The higher the temperature, the higher the average kinetic energy of the molecules and vice versa
 - This means they move **faster**
 - This applies to all states of matter, but the motion of particles in a solid is different to that of particles in a gas
- If the temperature of a gas is increased, the particles move faster and gain **kinetic energy**
 - Therefore, they will collide more with each other and the container leading to an increase in pressure
- The temperature (in Kelvin) is **proportional** to the average kinetic energy of the molecules

$$T \propto KE$$

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Worked example

When a liquid **evaporates**, molecules escape from the surface of the liquid. What happens to the temperature of the liquid and the average kinetic energy of the molecules within it?

	Temperature	Average kinetic energy of molecules
A	Increases	Increases
B	Decreases	Decreases
C	Stays the same	Decreases
D	Decreases	Increases

ANSWER: B

- When evaporation takes place, the more energetic molecules are leaving the surface of the liquid
- Since the more energetic molecules have left, the **average kinetic energy per molecule** must **decrease**
 - Therefore, **A** & **D** are not correct
- Temperature is **proportional** to the average kinetic energy per molecule, therefore the **temperature** also **decreases**


Your notes

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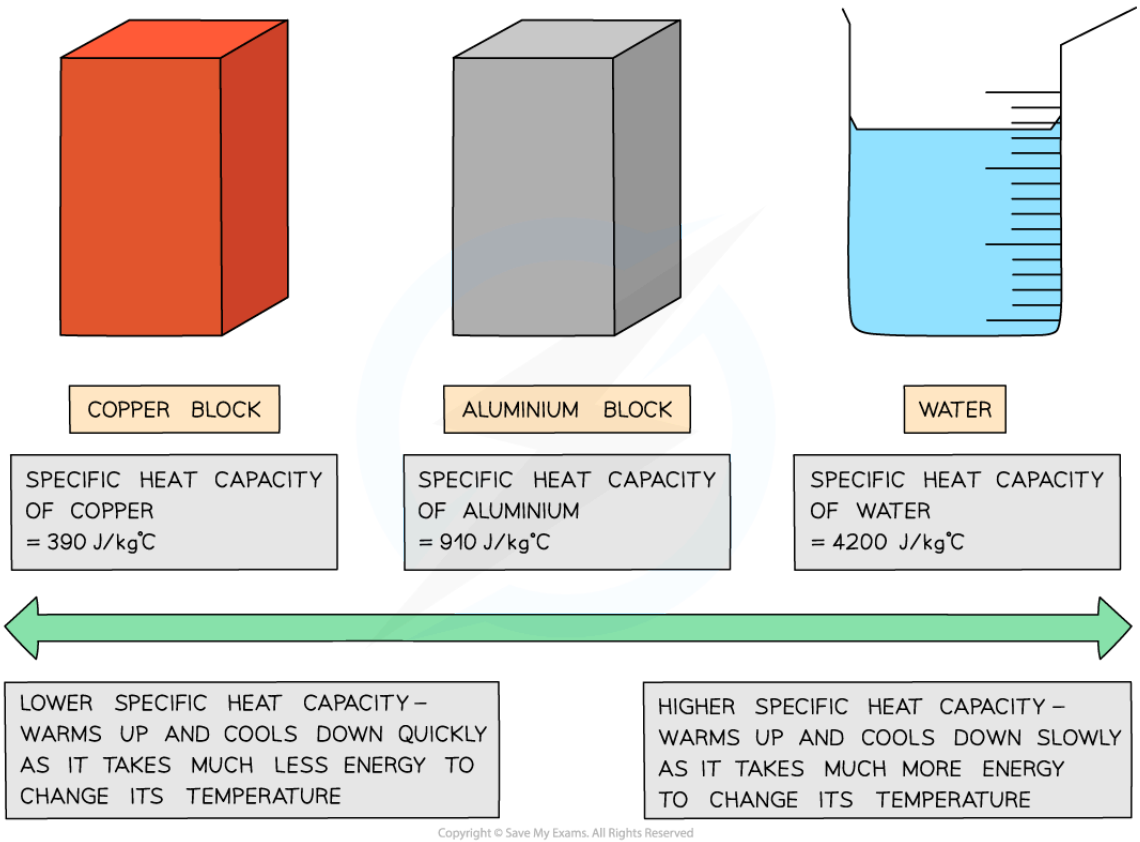
Specific Heat Capacity

Your notes

- How much the temperature of a system increases depends on:
 - The **mass** of the substance heated
 - The **type** of material
 - The amount of **thermal energy** transferred in to the system
- The **specific heat capacity**, c, of a substance is defined as:

The amount of energy required to raise the temperature of 1 kg of the substance by 1 °C

- Different substances have different specific heat capacities
 - If a substance has a **low** specific heat capacity, it heats up and cools down quickly (ie. it takes less energy to change its temperature)
 - If a substance has a **high** specific heat capacity, it heats up and cools down slowly (ie. it takes more energy to change its temperature)



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Low vs high specific heat capacity

Calculating Specific Heat Capacity

- The specific heat capacity in terms of the amount of energy needed to raise the temperature of a given mass by a given amount can be calculated using the equation:

$$c = \frac{\Delta E}{m\Delta\theta}$$

- Where:
 - ΔE = change in thermal energy, in joules (J)
 - m = mass, in kilograms (kg)
 - c = specific heat capacity, in joules per kilogram per degree Celsius (J/kg °C)
 - $\Delta\theta$ = change in temperature, in degrees Celsius (°C)

Worked example

Water of mass 0.48 kg is increased in temperature by 0.7 °C. The specific heat capacity of water is 4200 J / kg °C.

Calculate the amount of thermal energy transferred to the water.

Answer:

Step 1: Write down the known quantities

- Mass, m = 0.48 kg
- Change in temperature, ΔT = 0.7 °C
- Specific heat capacity, c = 4200 J/kg °C

Step 2: Write down the relevant equation

$$\Delta E = mc\Delta\theta$$

Step 3: Calculate the thermal energy transferred by substituting in the values

$$\Delta E = (0.48) \times (4200) \times (0.7) = 1411.2$$

Step 4: Round the answer to 2 significant figures and include the units

ΔE = 1400 J

Your notes

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Exam Tip

You will always be given the specific heat capacity of a substance, so you do not need to memorise any values.

However, it's useful to have the general idea that, the **larger the number**, the **less the substance will increase in temperature** for a given amount of heat.

You can see this for yourself in your own kitchen at home. Metal pans, which have a relatively low specific heat capacity get very hot, very quickly when put on the hob. Add water to the pan, which has a relatively high specific heat capacity and the water will take much longer to heat up.

Notice the **units** of specific heat capacity:

joules *per* kilogram *per* degree Celsius : J / kg °C

'per' means 'divided by'. We say 'per' in front of every value that is being divided by, hence 'per kilogram per degree Celsius'

Your notes

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Investigating Specific Heat Capacity


Your notes

Investigating Specific Heat Capacity (Extended)

Aims of the Experiment

- The aim of the experiment is to determine the specific heat capacity of a substance, by linking the decrease of one energy store (or work done) to the increase in temperature and subsequent increase in thermal energy stored

Variables

- Independent variable = Time, t
- Dependent variable = Temperature, θ
- Control variables:
 - Material of the block
 - Current supplied, I
 - Potential difference supplied, V

Equipment List

EquipmentPurposeSubstance to calculate the specific heat capacity1kg block of metal (e.g. aluminium), or, a beaker containing a known mass of waterThermometerTo measure the temperature rise of the substanceImmersion heaterTo heat the substancePower supplyTo supply power to the heaterStopwatchTo measure the time taken for the substance to heat up by a certain temperatureVoltmeterTo determine the potential difference through the heaterAmmeterTo determine the current from the power supply to the heater

Equipment	Purpose
1kg block of metal (e.g. aluminium), or, a beaker containing a known mass of water	Substance to calculate the specific heat capacity
Thermometer	To measure the temperature rise of the substance
Immersion heater	To heat the substance
Power supply	To supply power to the heater

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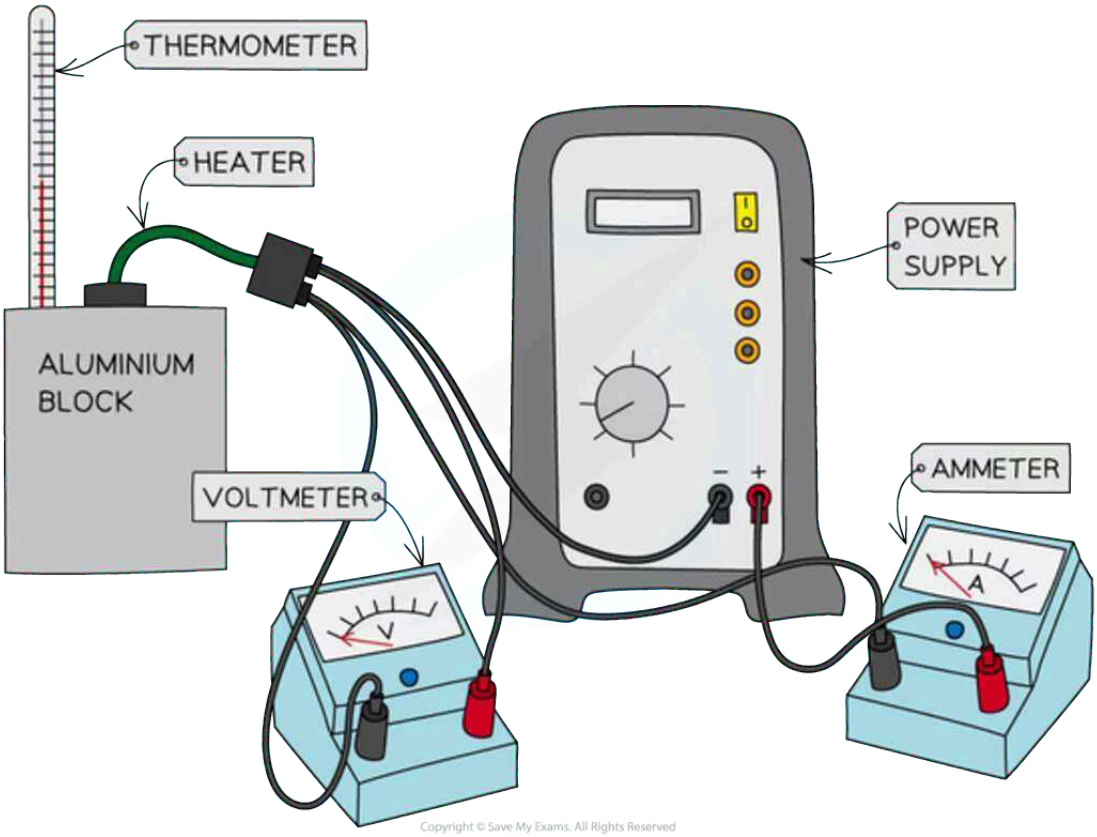
Stopwatch	To measure the time taken for the substance to heat up by a certain temperature
Voltmeter	To determine the potential difference through the heater
Ammeter	To determine the current from the power supply to the heater

Your notes

- Resolution of measuring equipment:
 - Thermometer = 1 °C
 - Stopwatch = 0.01 s
 - Voltmeter = 0.1 V
 - Ammeter = 0.01 A

Method

Apparatus to Measure Specific Heat Capacity



Apparatus to investigate the specific heat capacity of the aluminium block

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1. Start by assembling the apparatus, placing the heater into the top of the block
2. Measure the initial temperature of the aluminium block from the thermometer
3. Turn on the power supply and start the stopwatch
4. Whilst the power supply is on, the heater will heat up the block. Take several periodic measurements, eg. every 1 minute of the voltage and current from the voltmeter and ammeter respectively, calculating an average for each at the end of the experiment up to 10 minutes
5. Switch off the power supply, stop the stopwatch and leave the apparatus for about a minute. The temperature will still rise before it cools
6. Monitor the thermometer and record the final temperature reached for the block

Your notes

- An example table of results might look like this:

Example Results Table

TIME / s	POTENTIAL DIFFERENCE / V	CURRENT / A
60		
120		
180		
240		
300		
360		
420		
480		
540		
600		
AVERAGE		

INITIAL TEMPERATURE / °C	FINAL TEMPERATURE / °C

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Analysis of Results

- The thermal energy supplied to the block can be calculated using the equation:

$$E = IVt$$

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Your notes

- Where:
 - E = thermal energy, in joules (J)
 - I = current, in amperes (A)
 - V = potential difference, in volts (V)
 - t = time, in seconds (s)
- The change in thermal energy is defined by the equation:

$$\Delta E = mc\Delta\theta$$

- Where:
 - ΔE = change in thermal energy, in joules (J)
 - m = mass, in kilograms (kg)
 - c = specific heat capacity, in joules per kilogram per degree Celsius (J/kg °C)
 - $\Delta\theta$ = change in temperature, in degrees Celsius (°C)
- Rearranging for the specific heat capacity, c:

$$c = \frac{\Delta E}{m\Delta\theta}$$

- To calculate $\Delta\theta$:

$$\Delta\theta = \text{final temperature} - \text{initial temperature}$$

- To calculate ΔE:

$$\Delta E = IVt_f - IVt_i$$

- Where:
 - I = average current, in amperes (A)
 - V = average potential difference (V)
 - t_f = final time, in seconds (s)
 - t_i = initial time, in seconds (s)
- These values are then substituted into the specific heat capacity equation to calculate the specific heat capacity of the aluminium block

Evaluating the Experiment

Systematic Errors:

- Make sure the voltmeter and ammeter are initially set to zero, to avoid **zero error**

Random Errors:

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- Not all the heat energy supplied from the heater will be transferred to the block, some will go into the surroundings or heat up the thermometer
 - This means the measured value of the specific heat capacity is likely to be higher than what it actually is
 - To reduce this effect, make sure the block is fully insulated
- A **joulemeter** could be used to calculate energy directly
 - This would eliminate errors from the voltmeter, ammeter and the stopwatch
- Make sure the temperature value is read at eye level from the thermometer, to avoid **parallax error**
- The experiment can also be repeated with a beaker of water of equal mass, the water should heat up slower than the aluminium block


Your notes

Safety Considerations

- Make sure never to touch the heater whilst it is on, otherwise, it could burn skin or set something on fire
 - Run any burns immediately under cold running water for at least 5 minutes
- Allow time for all the equipment, including the heater, wire and block to cool before packing away the equipment
- Keep water away from all electrical equipment
- Wear eye protection if using a beaker of hot water

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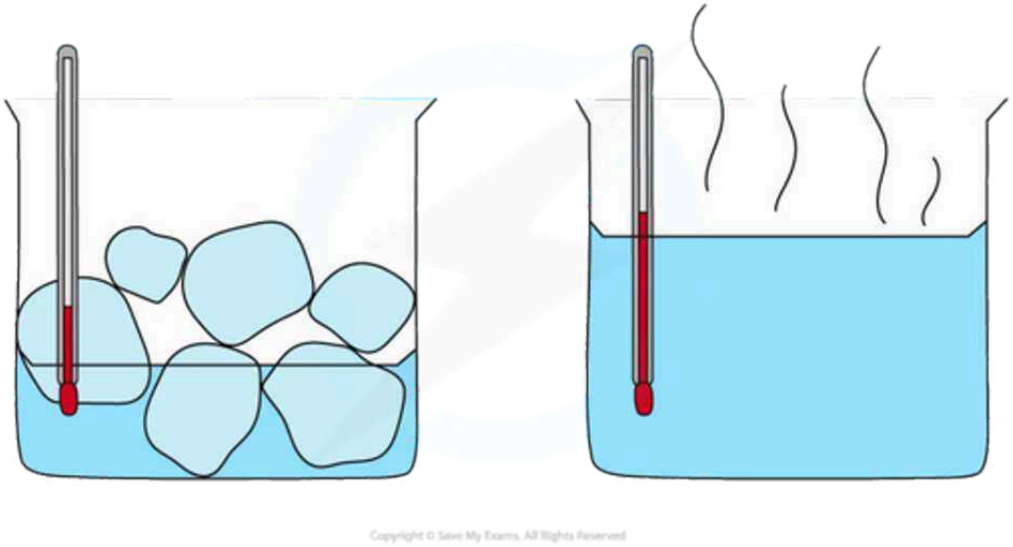
Melting, Boiling & Evaporation

Your notes

Fixed Points of Water

- The melting and boiling points of pure water are known as **fixed points**
 - Ice melts at 0 °C
 - Pure water boils at 100 °C
- These are the accepted values for **pure water** at **atmospheric pressure**

Ice Melting and Water Boiling



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Ice melts at 0 °C and water boils at 100 °C

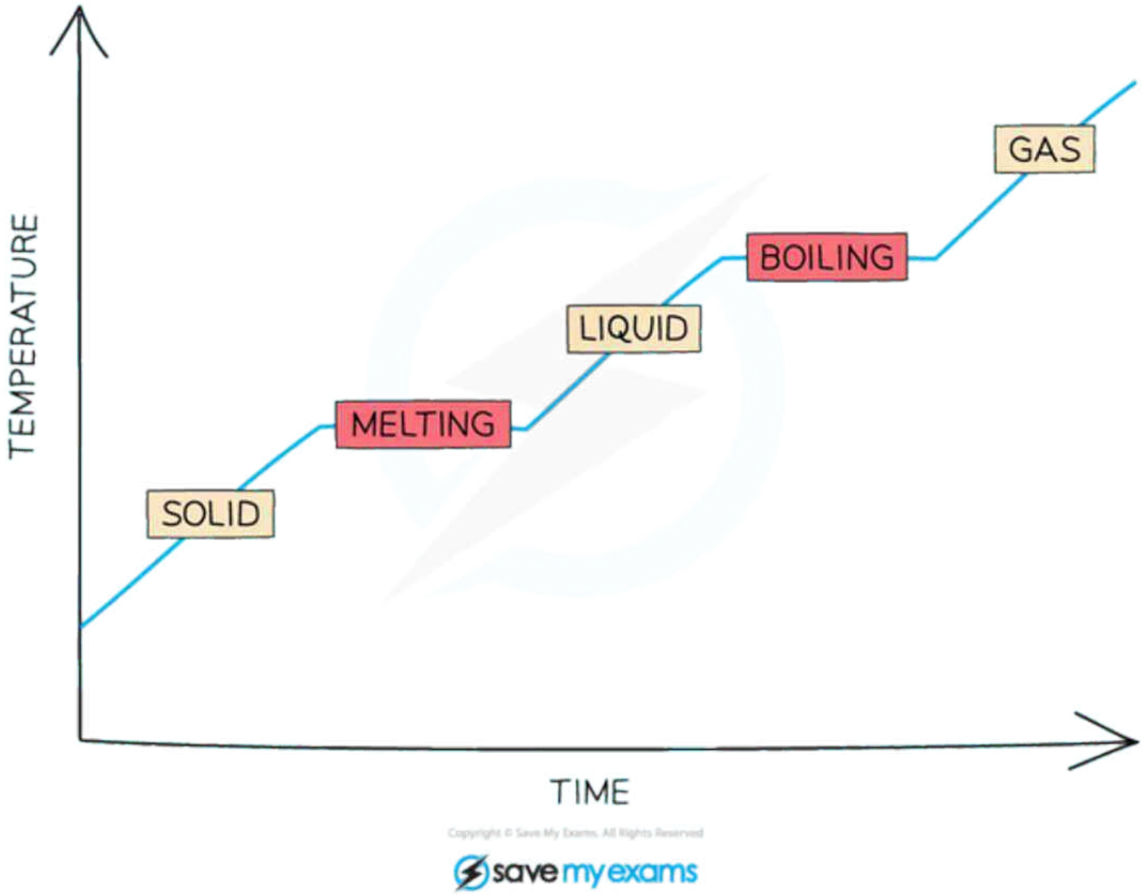
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Melting & Boiling

Your notes

- While a substance is **changing state**, either
 - Melting or freezing
 - Boiling or condensing
- The substance **does not change temperature,** even though energy is being transferred to or away from the thermal energy store of the substance

Changing Temperature through State Changes



Energy is transferred to the material over time. This causes an increase in temperature when the material is a solid, liquid or gas, but does not cause an increase in temperature when there is a change of state.

Boiling

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- When liquid water is heated by adding thermal energy (say from the gas flame or kettle element), the temperature of the water rises until the water boils
 - At the **boiling** point, even if more thermal energy is added, the liquid water does not get any hotter
 - This means that the internal energy is not rising
- The additional thermal energy goes into overcoming the intermolecular forces between the molecules of water
 - As the forces are overcome, the liquid water becomes water vapour (steam)
 - This is **evaporation** or vaporisation; the water is now a **gas**
- The process is repeated backwards for cooling as energy is transferred away
 - A gas turns back into liquid through **condensation**

Melting

- When solid water (ice) is heated by adding thermal energy (from the surroundings, or a flame), the ice melts
 - At the **melting** point, even if more thermal energy is added, the solid water does not get warmer
 - This means that the internal energy is not rising
- The additional thermal energy goes into overcoming the intermolecular forces between the molecules of the solid ice
 - As the forces are overcome, the solid water becomes liquid
 - This is **melting**; the ice is now a **liquid**
- The process is repeated backwards for cooling as heat is transferred away
 - A liquid turns back into a solid through **freezing**


Your notes

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Condensation & Solidification

Your notes

- Heating and cooling graphs are used to summarise:
 - How the temperature of a substance changes when energy is transferred to or away from it
 - Where changes of state occur
- Heating and cooling graphs tend to be the same
 - Heating is when energy is transferred **to** the system and the kinetic energy of the molecules increases (red arrows to the right)
 - Cooling is when energy is transferred **away from** the system (or dissipated to the surroundings) and the kinetic energy of the molecules decreases (blue arrows to the left)

Condensation

- The particle diagrams next to the graph show that as a gas condenses into a liquid
 - The gas has already lost heat energy (cooled down)
- The particles **lose kinetic energy** and move more slowly
 - They no longer have enough energy to overcome the **intermolecular forces** of attraction between molecules
 - The particles get **closer together**
 - They only have enough energy to **flow** over one another
- The gas has condensed into a liquid with **no change of temperature**

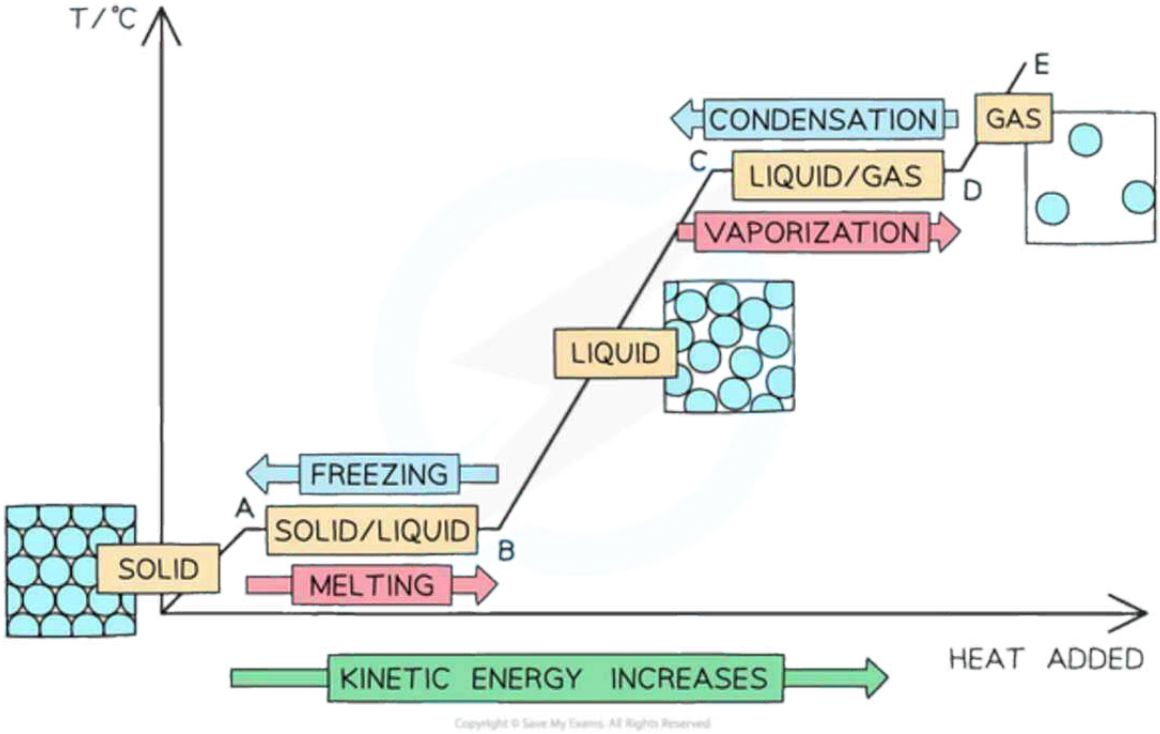
Solidification

- The particle diagrams next to the graph show that as a liquid solidifies into a solid
 - The liquid has already lost heat energy (cooled down)
- The particles **lose kinetic energy** and move more slowly
 - They no longer have enough energy to overcome the **intermolecular forces** of attraction between molecules
 - The particles get **closer together**
 - They only have enough energy to **vibrate** about their **fixed position**
- The liquid has solidified into a solid with no change of temperature

Heating / Cooling Graph

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Your notes



Heating/cooling curve of a substance showing the energy changes as temperature is increased/decreased

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Evaporation


Your notes

Boiling vs Evaporation

- Boiling is **also** a change in state from liquid to gas
 - Boiling happens only at the boiling point of the liquid
 - The change of state happens all through the liquid (seen as bubbles in boiling water, for example)

Comparing Evaporation and Boiling

	Evaporation	Boiling
Change of state?	Liquid to gas	Liquid to gas
Temperature at which this occurs?	At any temperature	Only at boiling point
From where in the liquid?	From the surface	Throughout the liquid

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Cooling by Evaporation

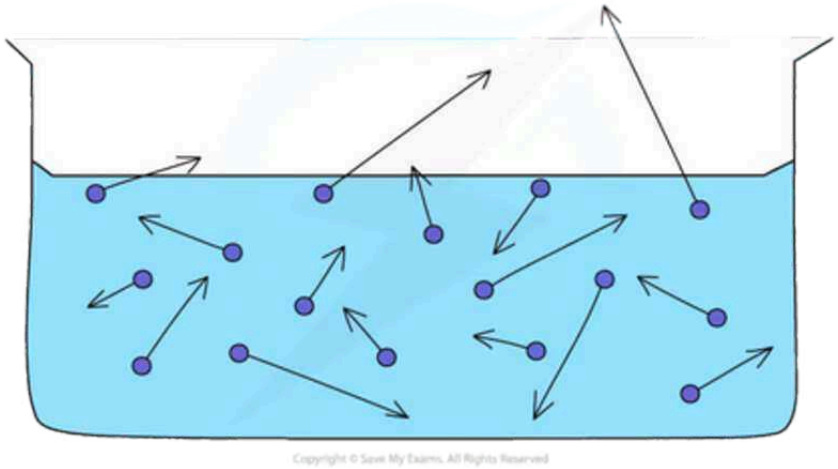
Your notes

- **Evaporation** is a change in state of a liquid to a gas
- It happens;
 - At any temperature
 - Only from the surface of a liquid

- The molecules in a liquid have a range of energies
 - Some have lots of energy, others have very little
 - Their **average energy** relates to the temperature of the liquid

- Evaporation occurs when **more energetic molecules** moving near the surface of the liquid have enough energy to escape
 - The average energy of the liquid is **reduced**
 - Therefore liquids are **cooled down** by evaporation

Process of Evaporation



Evaporation occurs when more energetic molecules near the surface of a liquid escape

Factors affecting the Rate of Evaporation

- The factors that affect the rate of evaporation are
 - Temperature
 - Surface area
 - Air movement

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Temperature

- Increased temperature increases the **kinetic energy** of the molecules in the liquid
 - Molecules with more energy are more likely to **overcome the intermolecular forces** holding them in the liquid state and escape the surface
 - Therefore **higher temperature** leads to a **higher rate of evaporation**

Surface Area

- Molecules only **escape** the intermolecular forces of attraction at the **surface** of the liquid
 - Therefore a **larger surface area** leads to a **higher rate of evaporation**

Air Movement

- Air movement carries away the water vapour which has just evaporated
 - This dries the air and allows more water molecules to escape
 - Therefore **increasing air movement** (when indoors this is sometimes called draughts) **increases the rate of evaporation**

Evaporation & Cooling

- The process of evaporation can be used to cool things down:
 - If an object is in contact with an evaporating liquid, as the liquid cools the solid will cool as well
 - This process is used in refrigerators and air conditioning units
 - This is also why sweating cools skin down - the water evaporates using energy from the body's thermal store


Your notes

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Cambridge O Level Physics

Your notes

2.3 Transfer of Thermal Energy

Contents

- Demonstrating Conduction
- Thermal Conduction
- Convection
- Radiation
- Investigating Radiation
- Consequences of Thermal Energy Transfer

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Demonstrating Conduction

Your notes

Experiments Demonstrating Thermal Conductors

- Good thermal conductors are solids which easily transfer heat
 - For example; a metal pan or a ceramic tea cup
- Bad thermal conductors (also called insulators) are solids which do not transfer heat well
 - For example; a woolen blanket or layers of cardboard or paper

Comparing Conduction in Tiles and Textiles

This demonstration shows why homes use rugs and carpets

- Find a tiled or stone area of floor
 - In the same room leave a rug or bath towel (not a thin cloth, it must be thick)
 - The textile must stay in place on the floor for several hours to ensure they are at thermal equilibrium (the same temperature)

Standing on a Tile and a Rug



One person with a foot on each allows a qualitative comparison of temperature between the two

- Stand with bare feet (hands can be used)
 - Place one foot on the tiles or stone area, and the other on the textile (towel or rug)
 - Observe the apparent temperature of the two materials as felt through the feet
 - It will feel as though the tiles are cold while the rug is warm, however, they are at exactly the same temperature

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Your notes

Transfer of Energy through Tile and Rug



Energy is transferred by heating from the warm body to the cooler tiles by conduction

Explanation

- Tiles and stone are good conductors of heat
 - Where the foot touches the tiles, **heat is transferred away** from the foot, making it **feel** cold
 - The **foot** has become colder since it lost heat to the tiles
- Textiles such as rugs are good insulators, meaning they are poor conductors of heat
 - Where the foot touches the rug, heat is not transferred away from the foot
 - This foot feels relatively warmer than the one which has lost heat to the tiles
 - The foot has stayed at its starting temperature

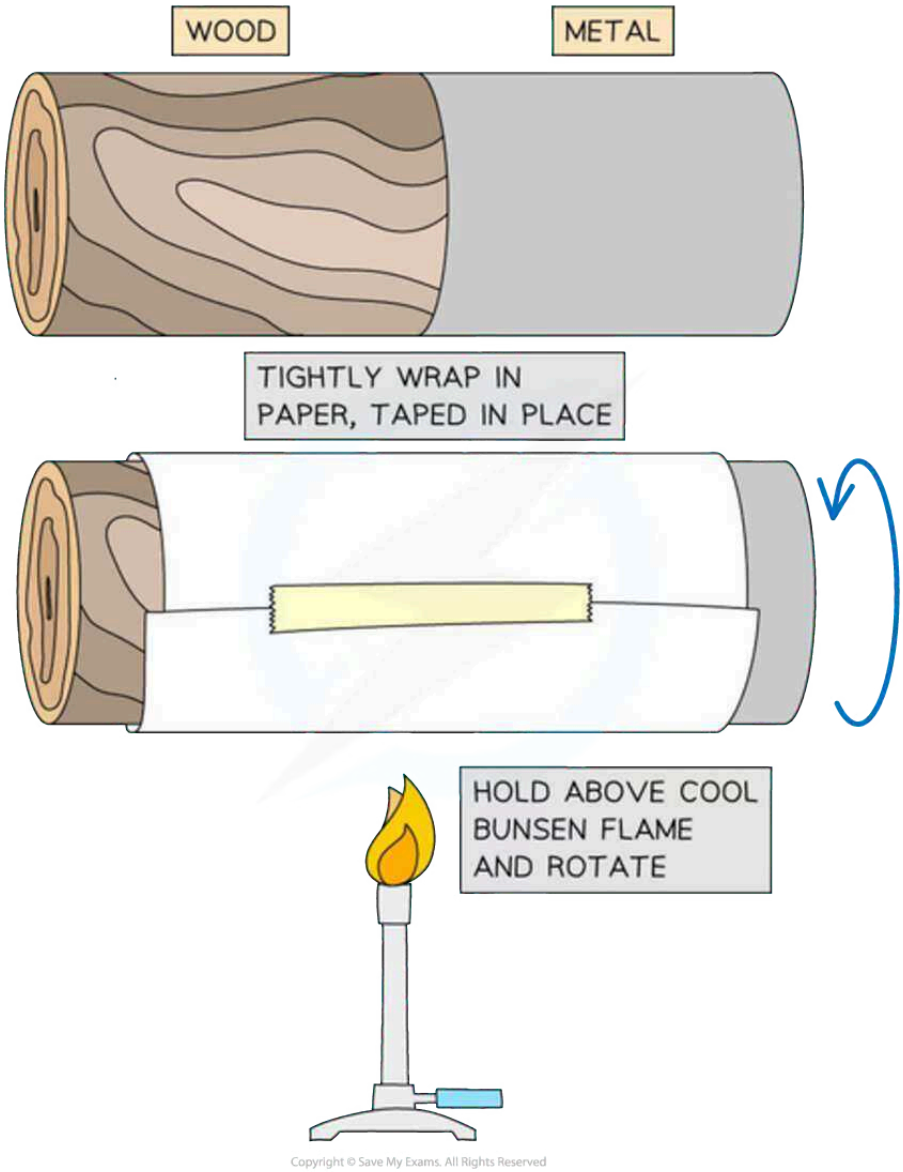
Comparing Conduction in Wood and Paper

- A cylindrical rod made of half wood and half metal is wrapped tightly in paper

Testing Conduction in Wood and Metal

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Your notes



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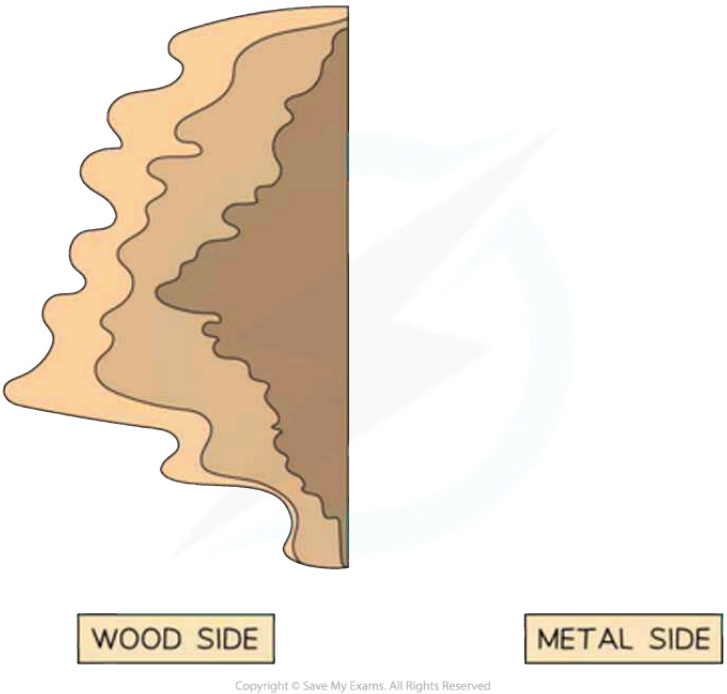
The paper is heated. The two different materials conduct energy away from the paper's thermal store at different rates

- Using a gentle flame, and holding the rod clear of the top of the flame, gently heat the paper at the join of the wood and metal
 - Turn the rod so that the paper is well-heated all around the circumference of the rod
 - Stop when the paper is clearly discoloured

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- Remove the rod from the flame, gently unwrap the paper and observe the burn pattern
 - A distinct pattern is seen;
 - Where the paper touched the metal surface it is undamaged
 - Where the paper touched the wood surface it is charred

Pattern of Charring on the Paper after the Experiment



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The side of the paper of the wood shows signs of being burned, so there was more energy in its thermal store on this side

Explanation

- Metal is a good conductor of heat
 - Where the paper touched the metal, heat was transferred from the paper into the metal and along the length of the metal
 - This prevented the paper getting hot
- Wood is a good insulator, meaning it is a poor conductor of heat
 - Where the paper touched the wood, heat was not transferred from the paper
 - This meant that the paper did get hot enough to start to burn

Demonstrating Different Rates of Thermal Conduction in Metals

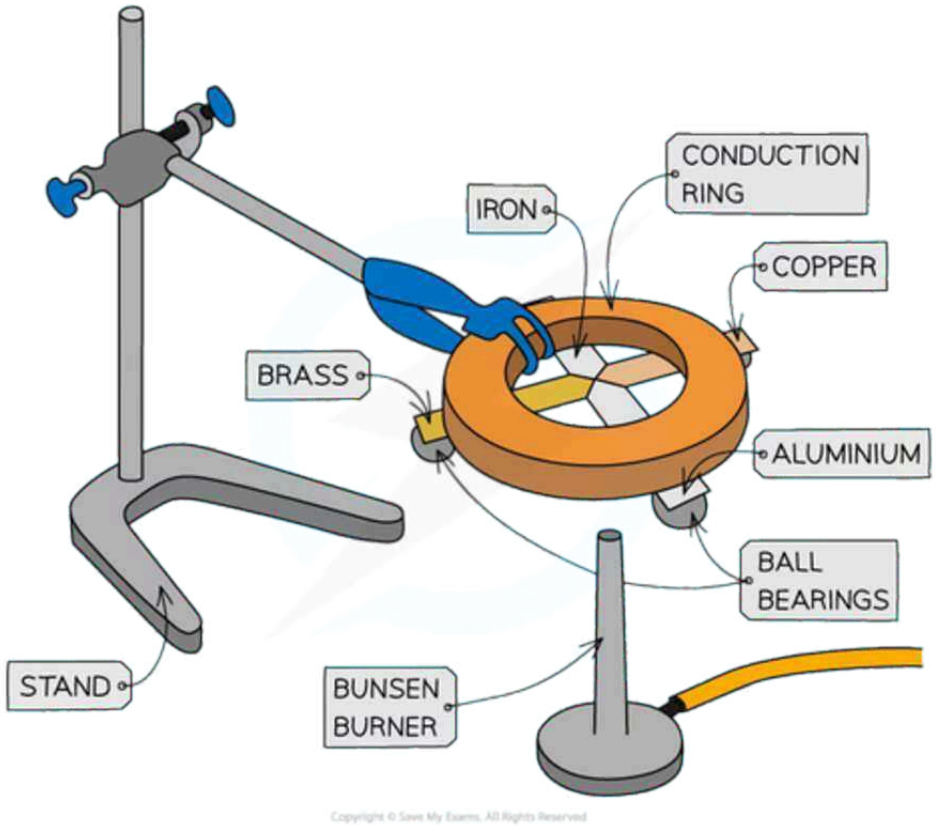
Your notes

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- A simple experiment to demonstrate the relative conducting properties of different materials can be carried out using apparatus similar to that shown in the diagram below

Your notes

Apparatus for Conduction Ring Experiment



The above apparatus consists of 4 different metal strips of equal width and length arrange around an insulated circle

- Ball bearings can be stuck to each of the strips and equal distance from the centre, using a small amount of wax
- The strips should then be turned upside down and the centre heated gently using a candle, so that each of the strips is heated at the point where they meet
- When the heat is conducted along to the ball bearing, the wax will melt and the ball bearing will drop
- By timing how long this takes for each of the strips, their relative thermal conductivities can be determined

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Exam Tip

With two of the demonstrations above (the rug & tiles and the rod made of wood and metal) students often get confused, as the result may 'feel' as though it is the wrong way round. Think about the movement or transfer of the heat.

The more heat is taken away, the cooler something will be. That is why the paper doesn't burn when it is next to the metal (although usually everyone guesses that it will!)

The more heat is held in by a layer of insulation, the more heat remains, which is why rugs and carpets help your feet to feel warm.



Your notes

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Thermal Conduction

Your notes

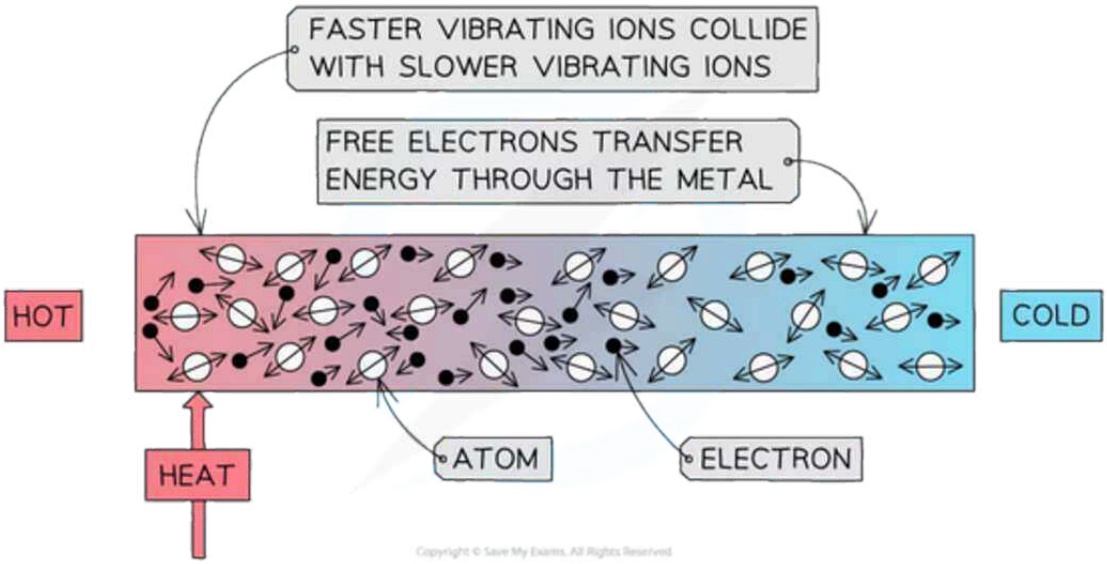
Thermal Conduction in Solids

- Conduction is the main method of thermal energy transfer in **solids**
- Conduction occurs when:

> **Two solids of different temperatures come in contact with one another, thermal energy is transferred from the hotter object to the cooler object**

- Metals are the best thermal **conductors**
 - This is because they have a high number of **free electrons**

Thermal Conduction in a Metal



Conduction: the atoms in a solid vibrate and bump into each other

- Conduction can occur through two mechanisms:
 - Atomic vibrations
 - Free electron collisions

- When a substance is heated, the atoms, or ions, **start to move around (vibrate) more**
 - The atoms at the hotter end of the solid will vibrate more than the atoms at the cooler end
 - As they do so they **bump into each other**, transferring energy from atom to atom
 - These collisions transfer internal energy until **thermal equilibrium** is achieved throughout the substance

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- This occurs in **all solids**, metals and non-metals alike


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Convection

Your notes

Convection

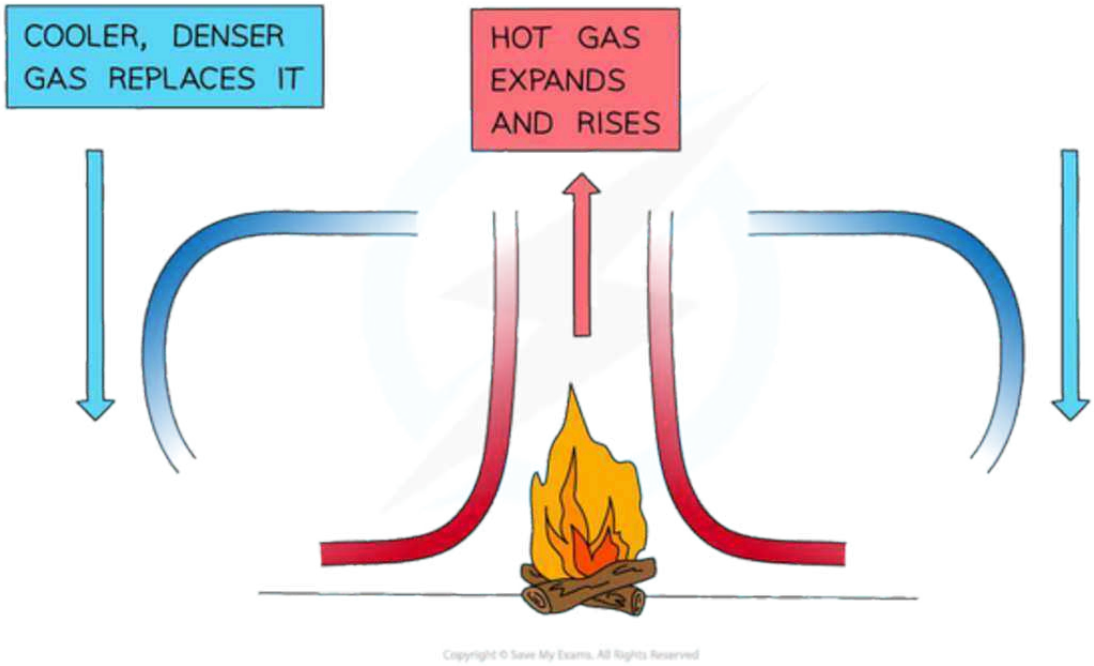
- Convection is the main way that heat travels through **liquids and gases**
 - Convection **only** occurs in fluids
 - Convection **cannot** happen in solids

Density & Convection

Descriptions of convection currents always need to refer to changes in temperature causing changes in density

 - The temperature may fall or rise, both can create a convection current
- **When a liquid (or gas) is heated (for example by a radiator near the floor)**:
 - The molecules push each other apart, **making the liquid/gas expand**
 - This makes the hot liquid/gas **less dense** than the surroundings
 - The **hot liquid/gas rises**, and the cooler (surrounding) liquid/gas moves in to take its place
 - Eventually the hot liquid/gas cools, contracts and sinks back down again
 - The resulting motion is called a **convection current**

Convection Currents



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When a liquid or gas is heated, it becomes less dense and rises

- **When a liquid (or gas) is cooled (for example by an A.C. unit high up on a wall)**:
 - The molecules move together, **making the liquid/gas contract**
 - This makes the hot liquid/gas **more dense** than the surroundings
 - The **cold liquid/gas falls**, so that warmer liquid or gas can move into the space created
 - The warmer liquid or gas gets cooled and also contracts and falls down
 - The resulting motion is called a **convection current**

Your notes

Demonstrating Convection Currents

- A simple demonstration of convection in liquids involves taking a beaker of water and placing a few crystals of potassium permanganate in it, to one side, as shown in the diagram above
- When the water is heated at that side, the potassium permanganate will dissolve in the heated water and rise along with the warmed water, revealing the convection current

Demonstrating Convection

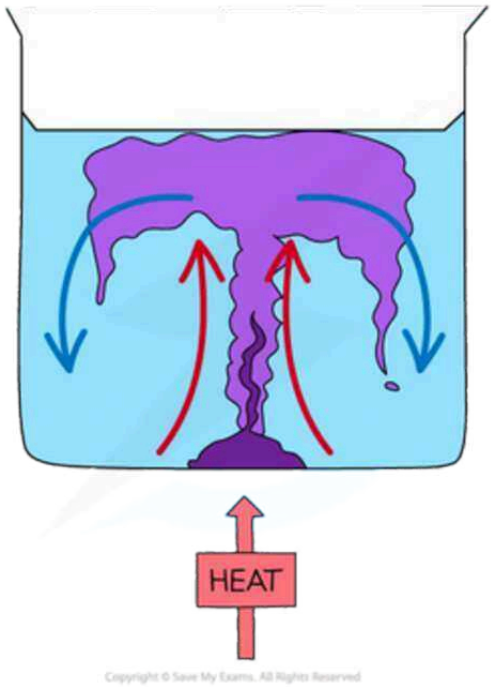


Diagram showing an experiment with potassium permanganate to demonstrate convection

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Exam Tip

If a question on heat mentions **liquids or gases** the answer will probably be about **convection**.

Heat does not rise - it is the hot gases or liquids which rise due to the change in density when they were heated.


Your notes

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Radiation

Your notes

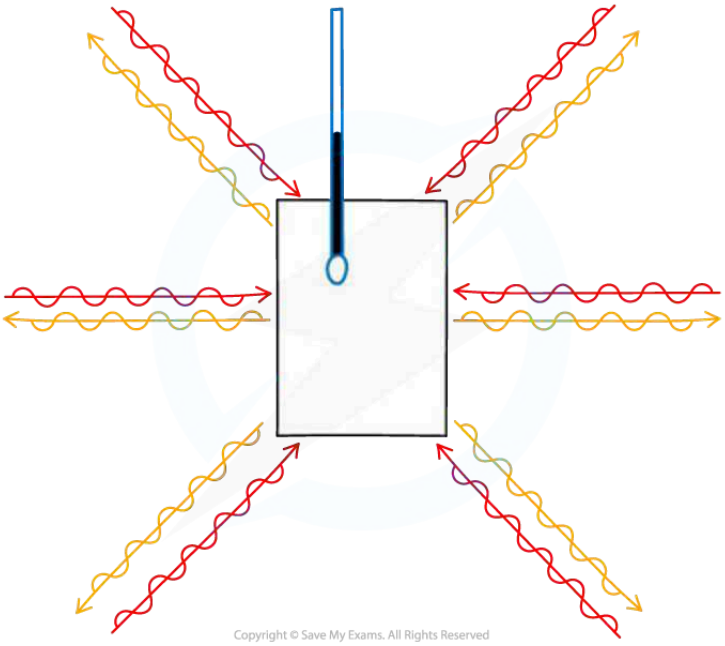
Thermal Radiation

- All objects give off thermal radiation
 - The hotter an object is, the more thermal radiation it emits
 - Thermal radiation is the part of the electromagnetic spectrum called **infrared**
- Thermal radiation is **the only way in which heat can travel through a vacuum**
 - It is the way in which heat reaches us from the Sun through the vacuum of space
- The colour of an object affects how good it is at emitting and absorbing thermal radiation:

Thermal Equilibrium

- As an object **absorbs** thermal radiation it will become **hotter**
- As it gets hotter it will also **emit** more thermal radiation
 - The temperature of a body increases when the body absorbs radiation faster than it emits radiation
- Eventually, an object will reach a point of **constant temperature** where it is **absorbing** radiation at the **same rate** as it is **emitting** radiation
 - At this point, the object will be in **thermal equilibrium**

Radiation in Equilibrium



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An object will remain at a constant temperature if it absorbs heat at the same rate as it loses heat

- If the rate at which an object receives energy is less than the rate at which it transfers energy away then the object will cool down
- If the rate at which an object transfers energy away is less than the rate at which it receives energy then the object will heat up
- The process will **always** move towards thermal equilibrium


Your notes

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Effects of Different Surfaces

Your notes

- The amount of thermal radiation emitted by an object depends on a number of factors:
 - The **surface colour** of the object (black = more radiation)
 - The **texture** of the surface (shiny surfaces = more radiation)
 - The **surface area** of the object (greater surface area = more area for radiation to be emitted from)

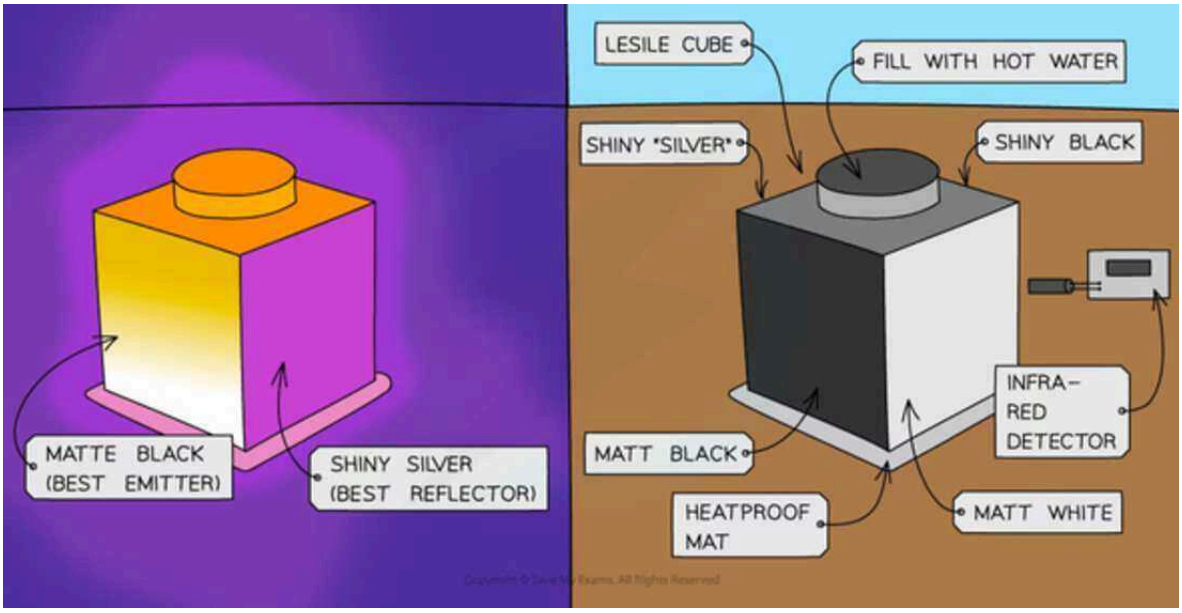
Absorbing and Emitting Powers of Different Coloured Objects

Colour	Absorbing	Emitting
Black	Good absorber	Good emitter
Dull / dark	Reasonable absorber	Reasonable emitter
White	Poor absorber	Poor emitter
Shiny	Very poor absorber (reflects radiation)	Very poor emitter

- Black objects are very good at absorbing thermal radiation, for example black clothes make you feel hotter in sunny weather
 - Black objects are also very good at emitting thermal radiation, which is the reason that chargers for laptops, and radiators in cars are coloured black - it helps them to cool down
- Shiny objects reflect thermal radiation and so absorb very little
 - They also emit very little, though, and so take longer to cool down

Leslie Cube Emission

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An image of a hot object taken in both Infrared and visible light. The black surface emits more thermal radiation (infrared) than the shiny surface

Your notes

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Investigating Radiation

Your notes

Investigating Thermal Radiation

Aims of the Experiment

The aim of the experiment is to investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface

Variables

- Independent variable = Colour
- Dependent variable = Temperature
- Control variables:
 - Identical flasks (except for their colour)
 - Same amounts of hot water
 - Same starting temperature of the water
 - Same time interval

Equipment List

Equipment	Purpose
Kettle	To boil water
4 thermometers	Measure the temperature of water
Flasks painted different colours (black, dull grey, white, silver)	Investigate heat loss in flasks of different colours
Heatproof mat	Protect surface and prevent heat loss from the bottom of the flasks
Stopwatch	Record time taken for water to cool

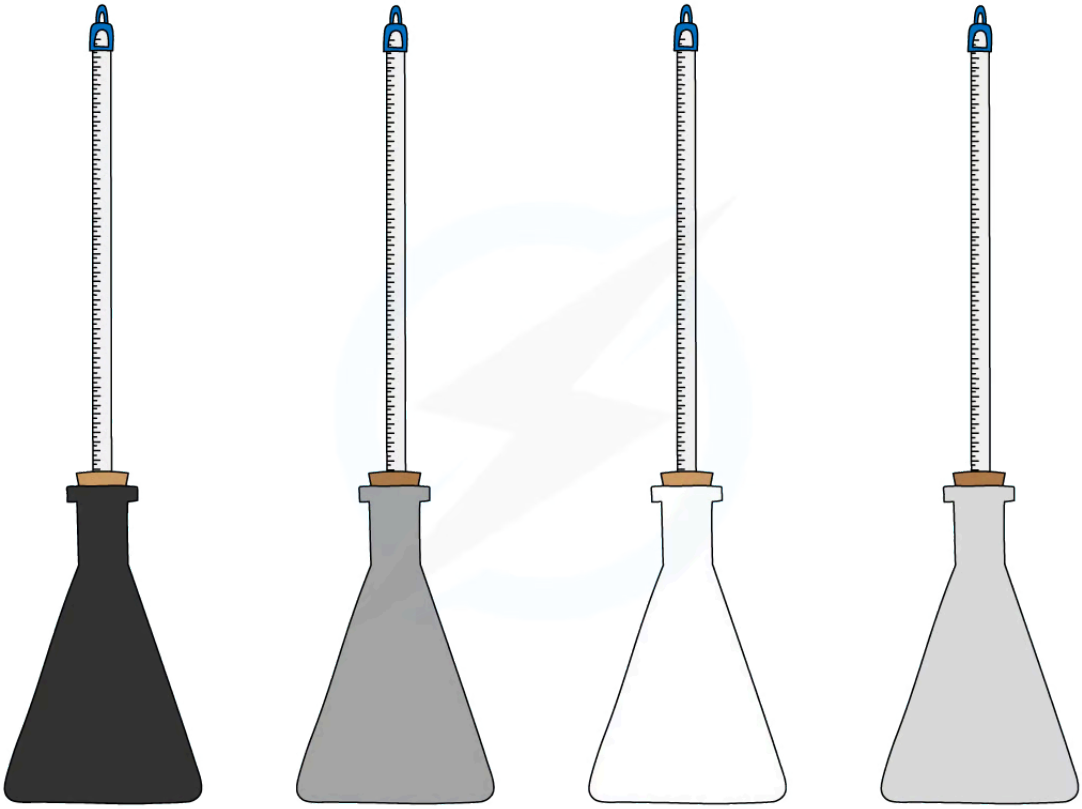
- Resolution of measuring equipment:
 - Thermometer = 1°C
 - Stopwatch = 0.01 s

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Method

Your notes

Four Flasks with Thermometers



1. Set up the four identical flasks painted black, grey, white and silver
2. Fill the flasks with hot water, ensuring the measurements start from the same initial temperature
3. Note the starting temperature, then measure the temperatures at regular intervals e.g. every 30 seconds for 10 minutes

Analysis of Results

- All warm objects emit thermal radiation in the form of **infrared** waves
- The intensity (and wavelength) of the emitted radiation depends on:
 - The **temperature** of the body (hotter objects emit more thermal radiation)
 - The **surface area** of the body (a larger surface area allows more radiation to be emitted)
 - The **colour** of the surface
- Most of the heat lost from the beakers will be due to conduction and convection
 - This will be the same for each beaker, as colour does not affect heat loss in this way

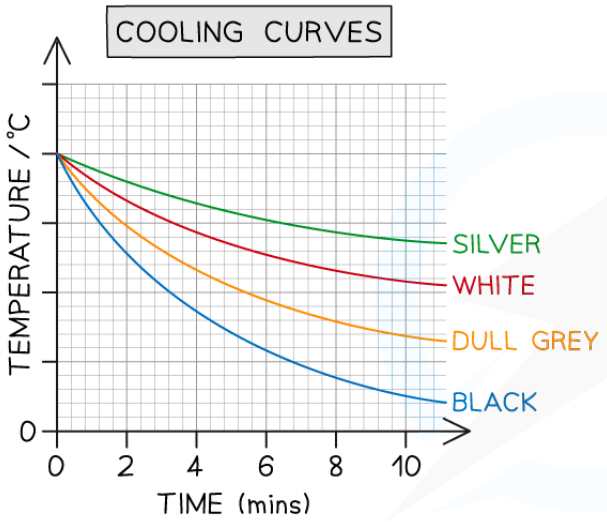
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- Any difference in heat loss between the beakers must, therefore, be due to infrared (thermal) radiation
- To compare the rate of heat loss of each flask, plot a graph of temperature on the y-axis against time on the x-axis and draw curves of best fit

Your notes

- The expected results are shown on the graph below:

Expected Results and Conclusions



Colour	Good or bad emitter?
Black	Good (cools fastest)
Dull grey	Reasonable (second fastest)
White	Poor (second slowest)
Silver	Very poor (cools slowest)

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- An example table of results might look like this:

Example Results Table

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TIME / mins	BLACK / °C	WHITE / °C	DULL GREY / °C	SILVER / °C
0.5				
1.0				
1.5				
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				
5.0				
5.5				
6.0				
6.5				
7.0				

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Your notes

Evaluating the Experiment

Systematic Errors:

- Make sure the starting temperature of the water is the same for each material since this will cool very quickly
 - It is best to do this experiment in pairs to coordinate starting the stopwatch and immersing the thermometer
- Use a data logger connected to a digital thermometer to get more accurate readings

Random Errors:

- Make sure the hole for the thermometer isn't too big, otherwise the heat will escape through the hole
- Take repeated readings for each coloured flask
- Read the values on the thermometer at eye level, to avoid parallax error

Safety Considerations

- Keep water away from all electrical equipment
- Make sure not to touch the hot water directly
 - Run any burns immediately under cold running water for at least 5 minutes
- Do not overfill the kettle

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- Make sure all the equipment is in the middle of the desk, and not at the end to avoid knocking over the beakers
- Carry out the experiment only whilst standing, in order to react quickly to any spills


Your notes

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Consequences of Thermal Energy Transfer

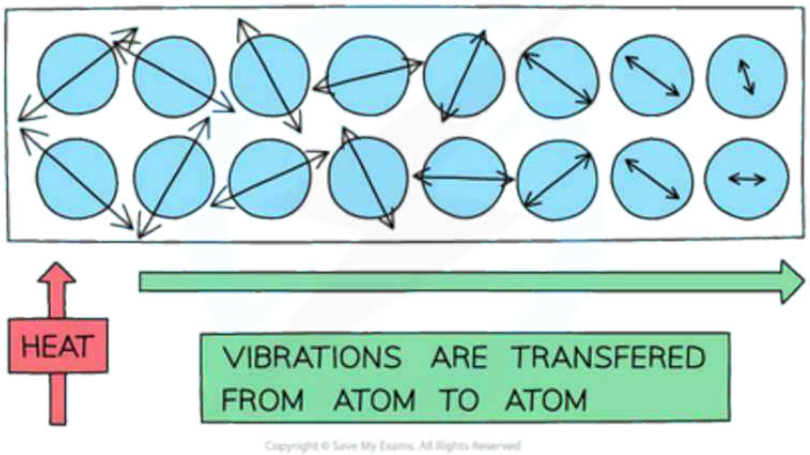
Your notes

Simple Consequences of Energy Transfer

Conduction

- **The main means of thermal energy transfer in solids**
- When heated, atoms vibrate more, knocking into each other and transferring energy from atom to atom as a result

Conduction in Solids

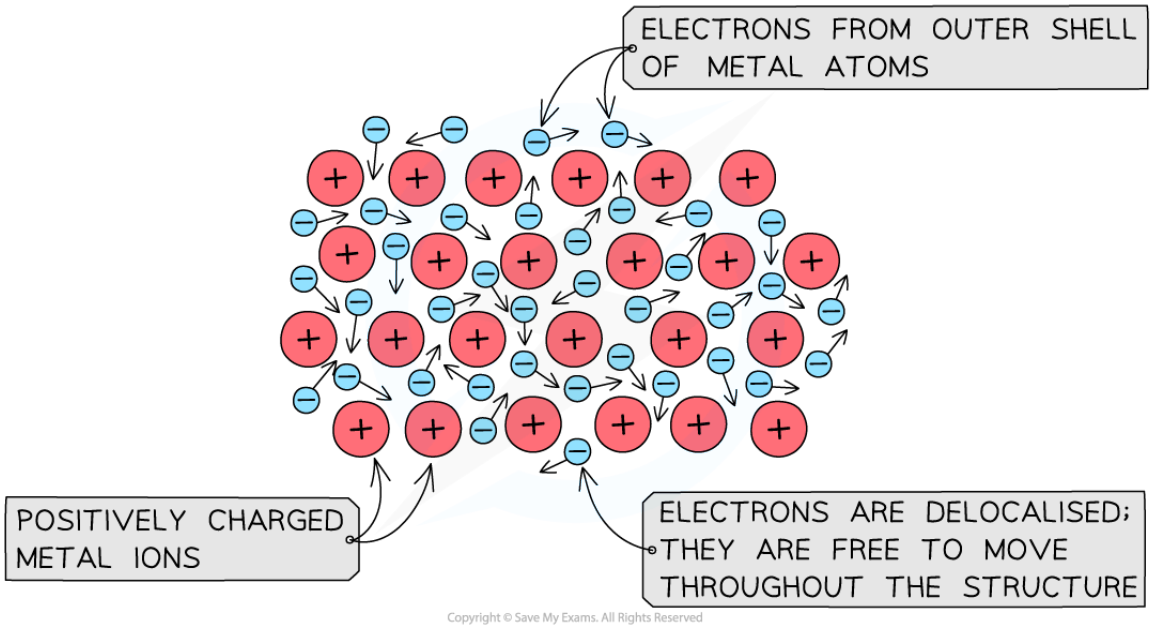


Energy from the kinetic store of a vibrating particle is transferred to the kinetic store of a neighbouring particle. In this way, energy is transferred throughout the solid.

- Metals are especially good at conducting heat as the **delocalised electrons** can collide with the atoms, helping to transfer the **vibrations** through the material and hence transfer heat better

Delocalised Electrons in a Metal

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Delocalised electrons in metals speed up thermal conduction

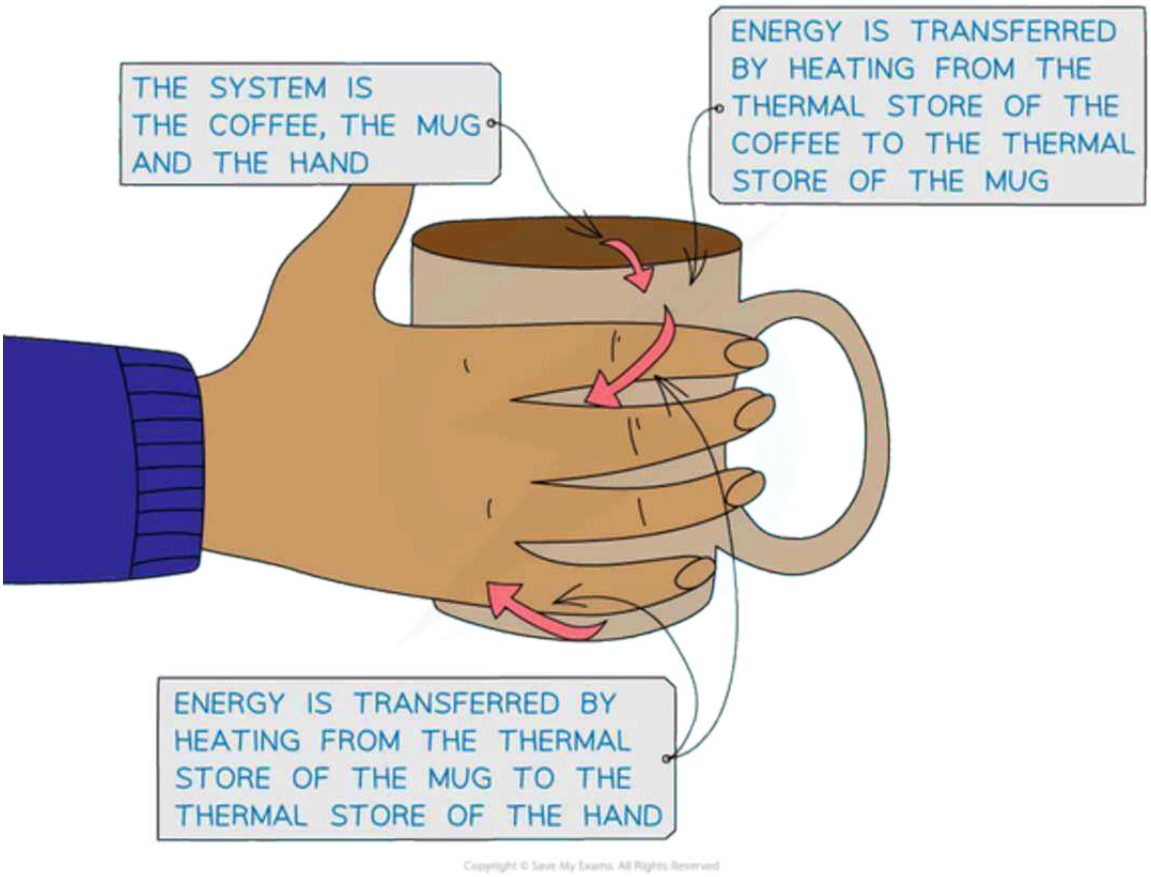
- If a question mentions **metals**, the answer will probably have something to do with conduction
- **Trapped air is a very good insulator**. Air is a gas and so is a poor conductor. Trapping air prevents it from circulating and forming a **convection** current

Hot Coffee Heating a Hand by Conduction

Your notes

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Your notes



Thermal energy is transferred from the hot coffee to the mug and to the cold hands

- Other common examples of conduction are:
 - Heating a pan on a hob
 - Heating water in a kettle
 - A lizard warming its belly on a hot rock

Convection

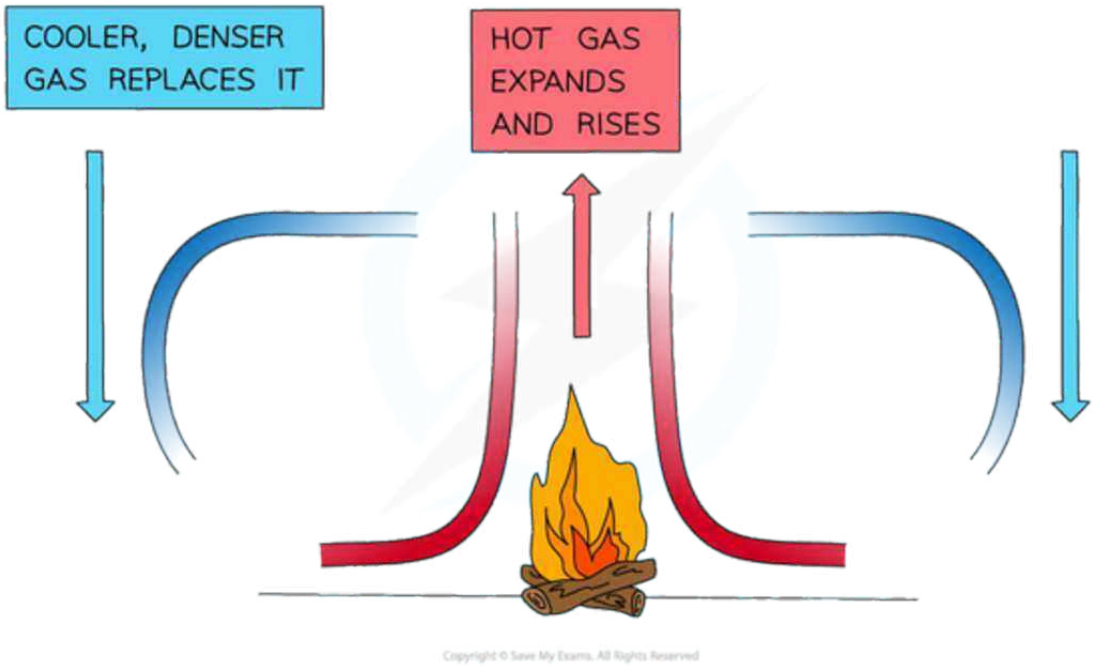
- **The means of thermal energy transfer in liquids and gases**
 - Convection **cannot occur in solids** because the in solids the particles are not free to move
- When a fluid (a liquid or a gas) is heated:
 - The molecules push each other apart, making the fluid **expand**
 - This makes the hot fluid **less dense** than the surroundings
 - The **hot fluid rises**, and the cooler (surrounding) fluid moves in to take its place

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- Eventually, the hot fluid cools, contracts and sinks back down again
- The resulting motion is called a **convection current**

Your notes

Convection Current



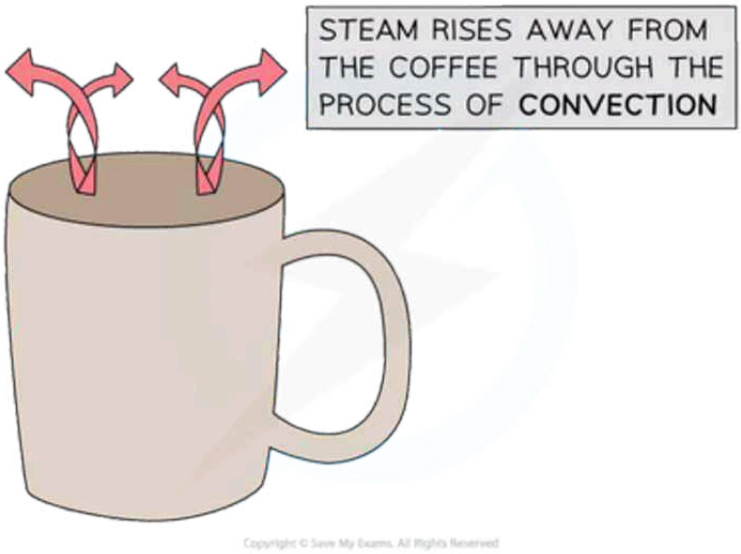
A convection current caused by heating from the fire

- **Heat sources placed at the bottom** of things will generally create convection currents. Likewise, **cooling units placed high up** will cool any rising air, causing it to sink again

Coffee Heats Air through Convection

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Your notes



Thermal energy is transferred from the hot coffee to the air by convection currents rising from the surface

- Other common examples of convection are:
 - A radiator heating a room
 - Air conditioning cooling a room
 - Ice cubes cooling a drink
 - A hot air balloon

Exam Tip

If a question is about a metal, then make sure you talk about **conduction**. If a question refers to a liquid or gas (that isn't trapped) then make sure you talk about **convection**.

Thermal Radiation

- **The only means of thermal energy transfer that does not require a medium**
- The temperature of a body can be regulated by balancing how much incoming radiation is absorbed and emitted (or reflected)
- If an object starts to absorb radiation at a higher rate than it radiates it, then the object will **heat up**
 - Likewise, if it loses radiation at a greater rate than it absorbs it, then the object will **cool down**
- This is how an emergency blanket works, to keep a trauma victim warm:
 - Rescue teams use light-coloured, shiny emergency blankets to keep accident survivors warm

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- A light, shiny outer surface emits a lot less radiation than a dark, matt (non-glossy) surface
- This keeps the patient warm, as less infrared radiation is emitted than if an ordinary blanket had been used

Your notes

Reflective Blanket Being Used to Keep a Patient Warm



The reflective surface of an emergency blanket reflects the infrared radiation emitted by the body back towards the patient, helping to keep them warm

- Other common examples of thermal radiation are:
 - Heating from sunlight
 - Using an infrared thermometer to measure temperature
 - Using a thermal imaging camera
 - Using night vision

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Complex Consequences of Energy Transfer

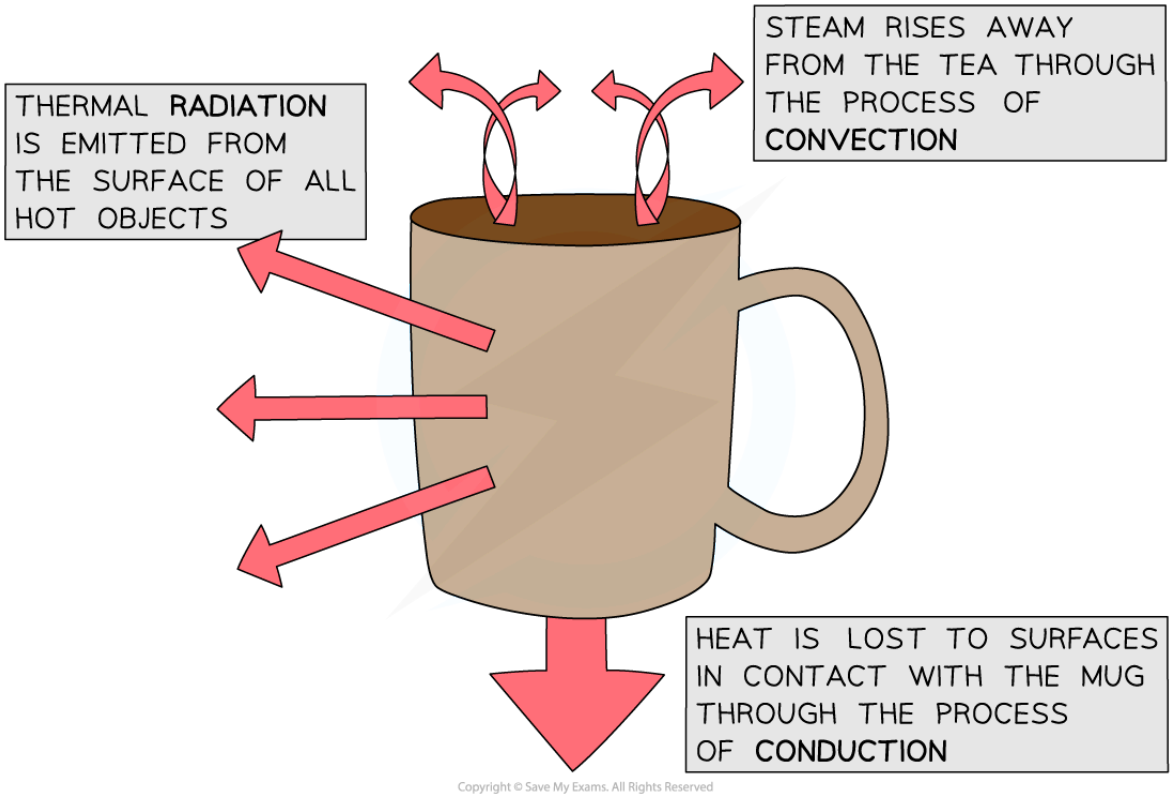
Your notes

- In real situations there is very rarely only one form of energy transfer
 - Usually all three happen at once

Thermal Energy Transfers in a Hot Drink

- In the diagram below a more complex - and more 'real' - version of the coffee cup is shown
- Thermal energy is transferred **from hotter areas (the tea) to cooler areas (the cup, hands and air)** by the processes of:
 - **Conduction**; by **direct contact** between the tea and the **solid** sides of the cup and also by direct contact from the cup to the surface it is sitting on
 - **Convection**; from the **surface** of the coffee to the air **directly above** it
 - **Radiation**; from the sides of the **hot cup** in **all directions** to the surrounding air

Thermal Energy Transfers Occurring in a Hot Drink



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Energy is transferred by conduction, convection and radiation from a hot mug of coffee

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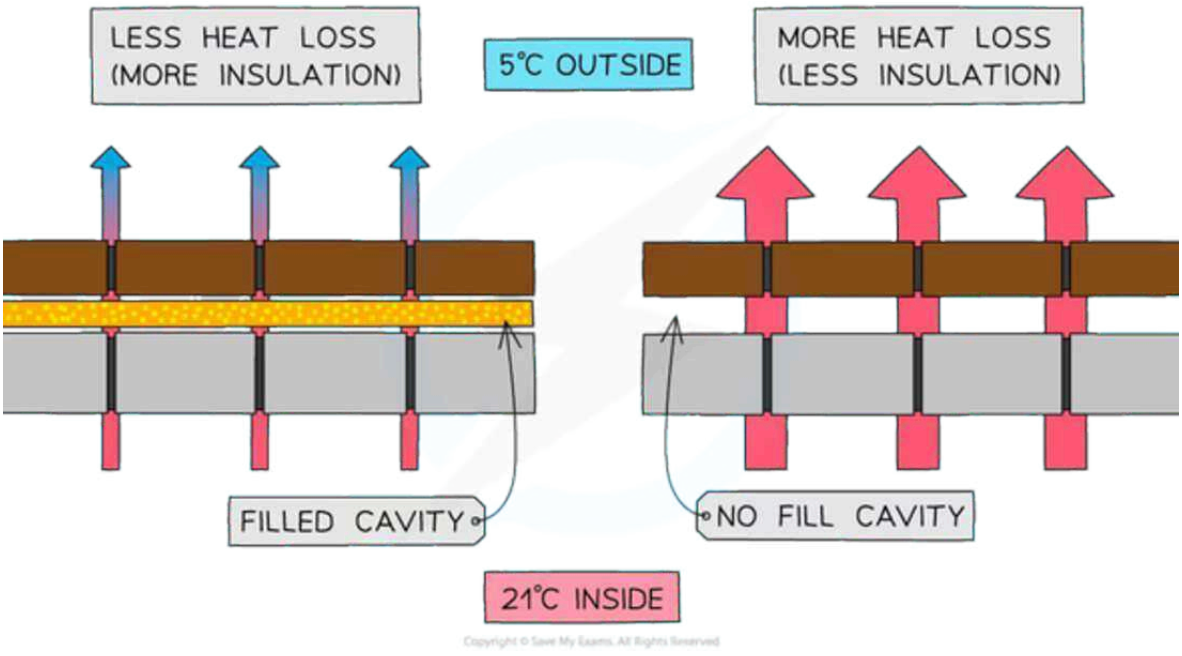
- Objects will **always** lose heat until they are in thermal equilibrium (same temperature) with their surroundings
 - For example, a mug of hot tea will cool down until it reaches room temperature
 - Eventually the room, tea and cup will **all** be at the same temperature

Your notes

Insulation in the Home

- Insulating the loft of a house lowers its rate of cooling, meaning less energy is lost to the outside
- The insulation is often made from fibreglass (or glass fibre)
 - This is a reinforced plastic material composed of woven material with glass fibres laid across and held together
 - The air trapped between the fibres makes it a **good** insulator
 - Trapped pockets of air ensure that convection currents **cannot** be formed, therefore reducing energy transfer by **convection**
- It has a much lower thermal conductivity than the roof material
- Several layers of insulation make it very thick and therefore **decrease** the rate of cooling

Cavity Wall Insulation



Less heat is lost from a building with the help of insulation (filled cavity in walls)

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Exam Tip

A **common mistake** made by candidates when explaining how an insulator keeps something warm is to state something along the lines of "The object warms up the insulator which then warms the object up".

Avoid giving this kind of answer!

The real explanation is:

- The insulator contains trapped air, which is a poor conductor of heat
- Trapping the air also prevents it from transferring heat by convection
- This reduces the rate of heat loss from the object, meaning that it will stay warmer for longer

Other things to watch out for:

- **Heat does not rise** (only hot gases or liquids rise)
- **Shiny things do not reflect heat** (they reflect thermal radiation)
- **Black things do not absorb heat** (they absorb thermal radiation)

And remember, a good answer will often include references to more than one method of thermal energy transfer.



Your notes

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Cambridge O Level Physics

Your notes

3.1 General Properties of Waves

Contents

- Features of Waves
- The Wave Equation
- Transverse & Longitudinal Waves
- Wave Behaviour
- Ripple Tank

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Features of Waves


Your notes

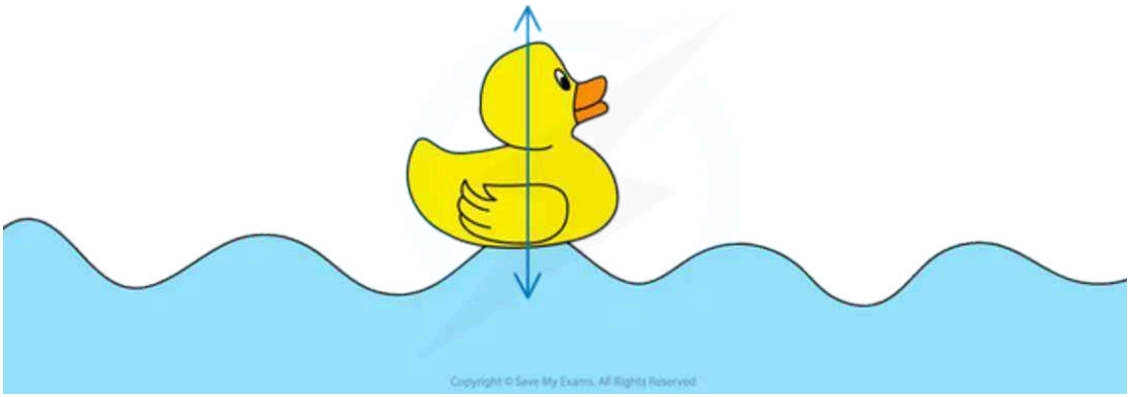
Waves – Basic

- Waves transfer **energy** and **information**
- Waves are described as **oscillations** or **vibrations** about a fixed point
 - For example, **ripples** cause particles of water to oscillate up and down
 - **Sound** waves cause particles of air to vibrate back and forth
- In all cases, waves transfer **energy without** transferring **matter**
 - For water waves, this means it is the **wave** and not the **water** (the matter) itself that travels
 - For sound waves, this means it is the **wave** and not the **air molecules** (the matter) itself that travels
- Objects floating on water provide evidence that waves only transfer energy and **not** matter

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Worked example

The diagram below shows a toy duck bobbing up and down on top of the surface of some water, as waves pass it underneath.



Explain how the toy duck demonstrates that waves do not transfer matter.

Answer:

Step 1: Identify the type of wave

- The type of wave on the surface of a body of water is a **transverse** wave
- This is because the duck is moving **perpendicular** to the direction of the wave

Step 2: Describe the motion of the toy duck

- The plastic duck moves up and down but does not travel with the wave

Step 3: Explain how this motion demonstrates that waves do not transfer matter

- Both transverse and longitudinal waves transfer **energy**, but not the particles of the medium
- This means when a wave travels between two points, no matter actually travels with it, the points on the wave just vibrate back and forth about **fixed** positions
- Objects floating on the water simply bob up and down when waves pass under them, demonstrating that there is **no movement of matter** in the direction of the wave, only **energy**

Exam Tip

There is a key distinction between the particles (or oscillations) of a wave, and the wave itself.

The motion of the wave **causes** the particles to move. The particles themselves are not the wave.

Your notes

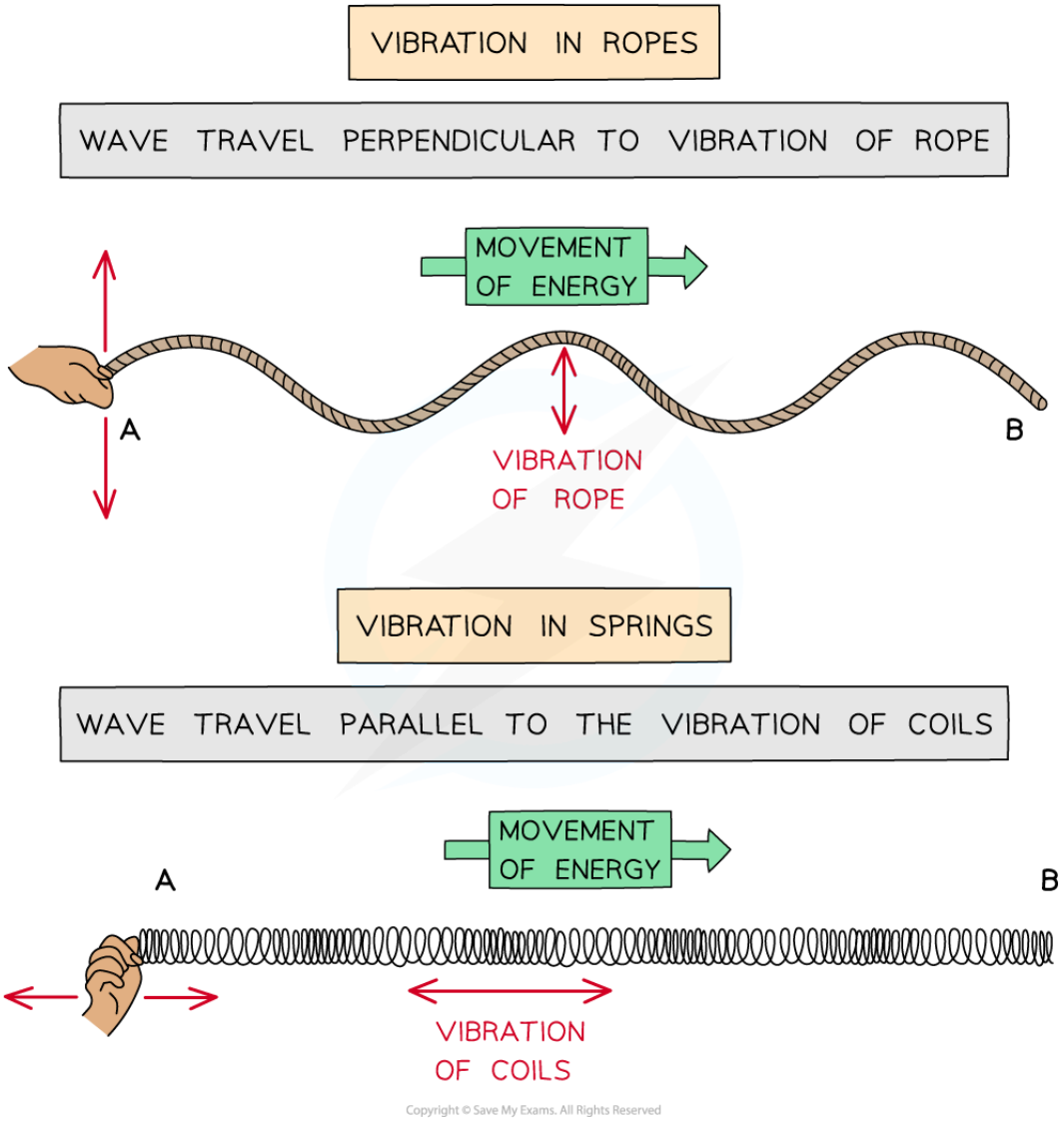
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Wave Motion

Your notes

- Wave vibrations can be shown on **ropes** (transverse) and **springs** (longitudinal)

Motion of Transverse and Longitudinal Waves



Waves can be shown through vibrations in ropes or springs

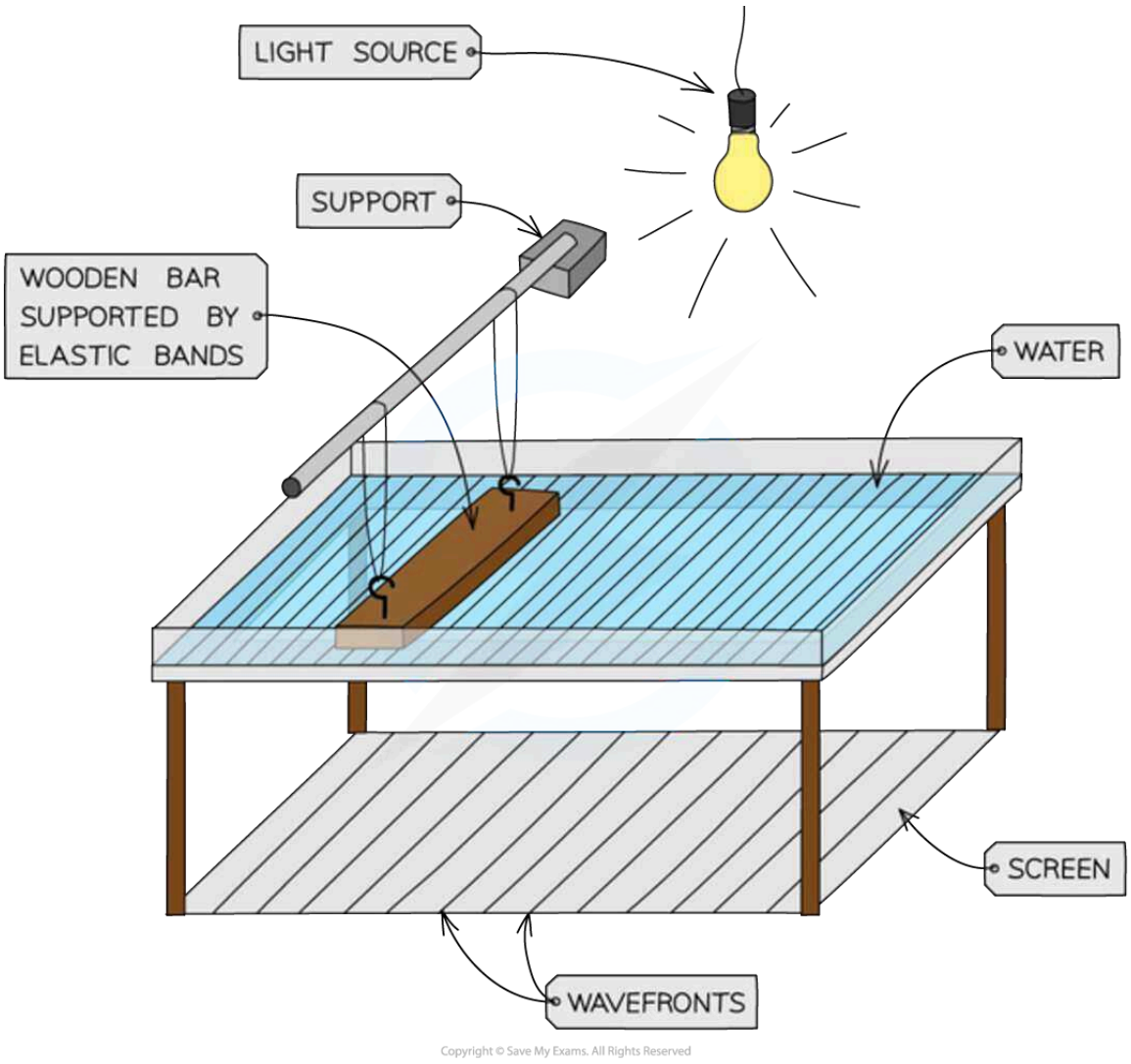
Demonstrating Wave Motion

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- Properties of waves, such as frequency, wavelength and wave speed, can be observed using water waves in a ripple tank

Your notes

Ripple Tank



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Wave motion of water waves may be demonstrated using a ripple tank

- The **wavelength** of the waves can be determined by:
 - Using a ruler to measure the length of the screen
 - Dividing this distance by the number of wavefronts
- The **frequency** can be determined by:
 - Timing how long it takes for a given number of waves to pass a particular point

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- Dividing the number of wavefronts by the time taken
- The **wave speed** can then be determined by:
 - Using the equation *wave speed = frequency × wavelength*


Your notes

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Features of a Wave

Your notes

- When describing wave motion, there are several terms which are important to know, including:
 - Crest (Peak)
 - Trough
 - Amplitude
 - Wavelength
 - Frequency
 - Wave speed
 - Wavefront

Crests & Troughs

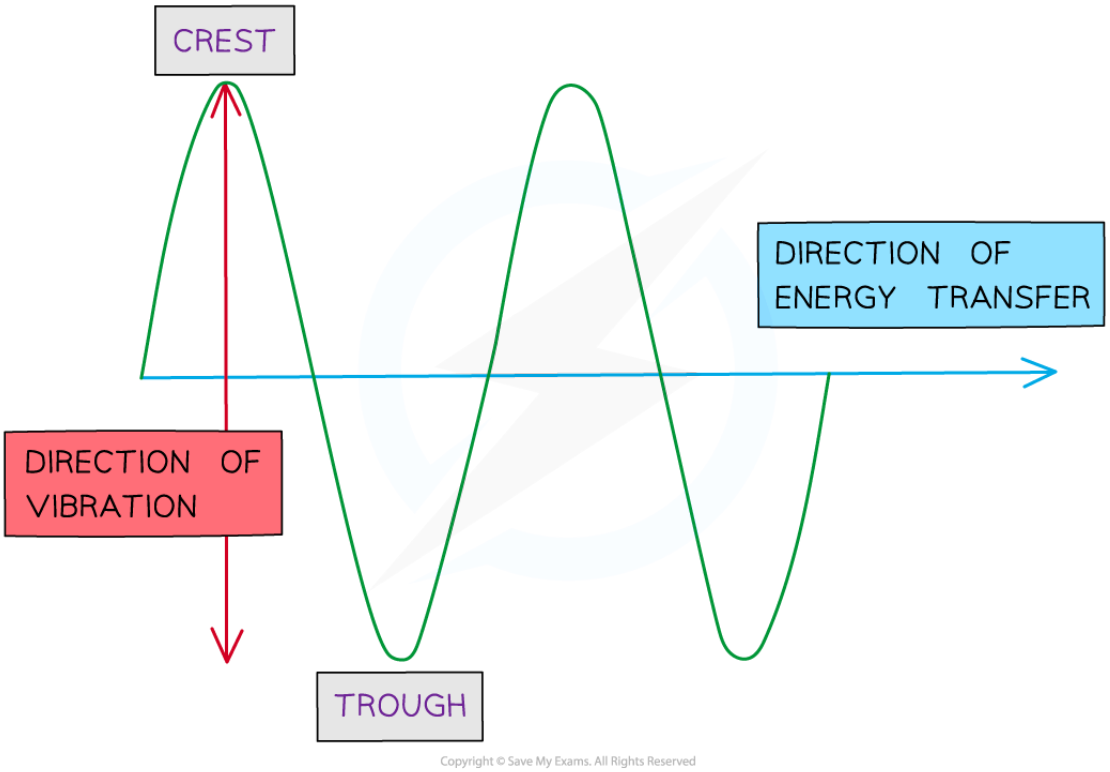
- A crest, or a peak, is defined as:

 The highest point on a wave above the equilibrium, or rest, position

- A trough is defined as

 The lowest point on a wave below the equilibrium, or rest, position

Crest and Trough of a Wave



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Diagram showing a crest and a trough on a transverse wave

Your notes

Amplitude

- Amplitude is defined as:
 The distance from the undisturbed position to the peak or trough of a wave
- It is given the symbol **A** and is measured in **metres (m)**
- Amplitude is the maximum or minimum **displacement** from the **undisturbed position**

Wavelength

- Wavelength is defined as:
 The distance from one point on the wave to the same point on the next wave
- In a transverse wave:
 - The wavelength can be measured from one peak to the next peak
- In a longitudinal wave
 - The wavelength can be measured from the centre of one compression to the centre of the next
- The wavelength is given the symbol **λ** (lambda) and is measured in **metres (m)**
- The distance along a wave is typically put on the x-axis of a wave diagram

Wavelength and Amplitude

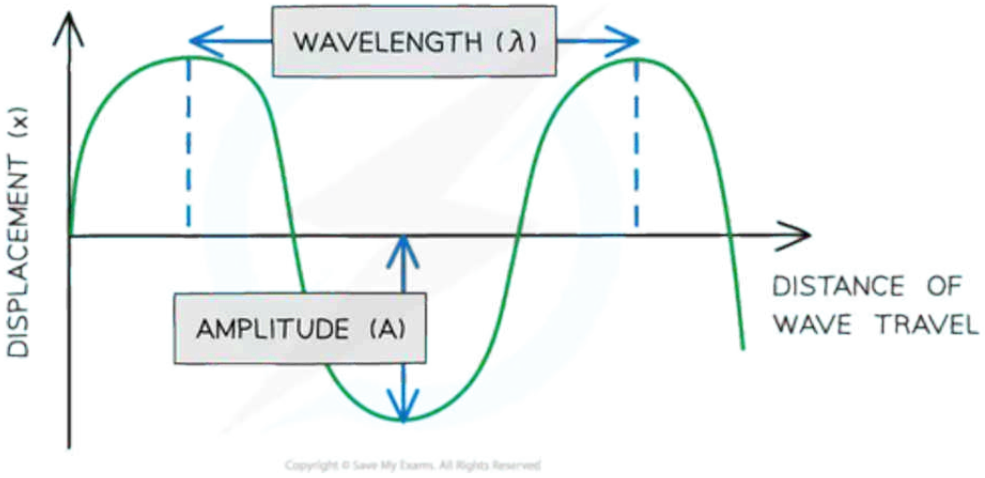


Diagram showing the amplitude and wavelength of a wave

Frequency

- Frequency is defined as:

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The number of waves passing a point in a second

- Frequency is given the symbol ***f*** and is measured in **Hertz (Hz)**


Your notes

Wave Speed

- Wave speed is the speed at which **energy** is transferred through a medium
- Wave speed is defined as:

The distance travelled by a wave each second

- Wave speed is given the symbol, *v*, and is measured in **metres per second (m/s),** it can be calculated using:

$$wave\ speed = frequency \times wavelength$$

Wavefronts

- Wavefronts are a useful way of picturing waves from above: each wavefront is used to represent a single wave
- The image below illustrates how wavefronts are visualised:
 - The arrow shows the direction the wave is moving and is sometimes called a **ray**
 - The space between each wavefront represents the **wavelength**
 - When the wavefronts are **close together**, this represents a wave with a **short** wavelength
 - When the wavefronts are **far apart**, this represents a wave with a **long** wavelength

Wavefronts

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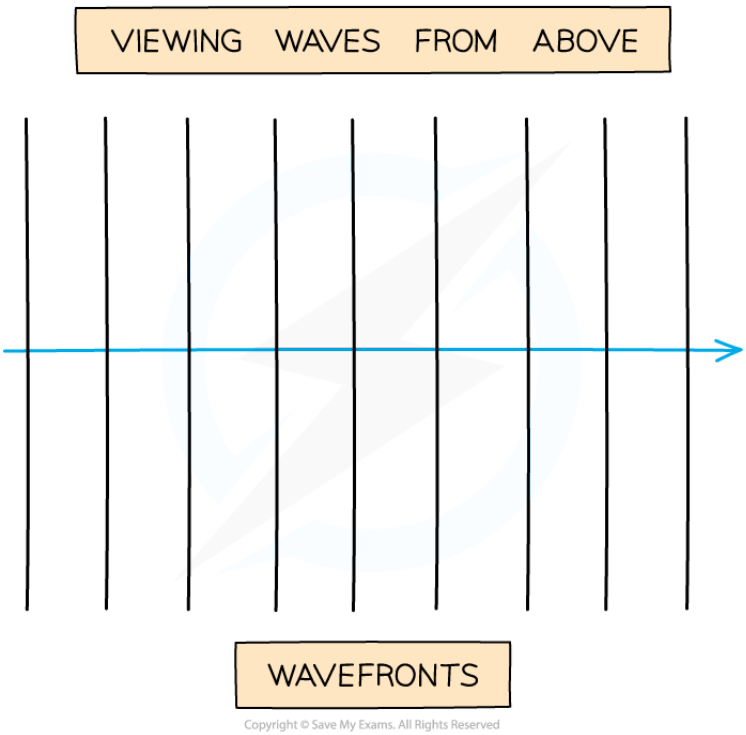


Diagram showing a wave moving to the right, drawn as a series of wavefronts

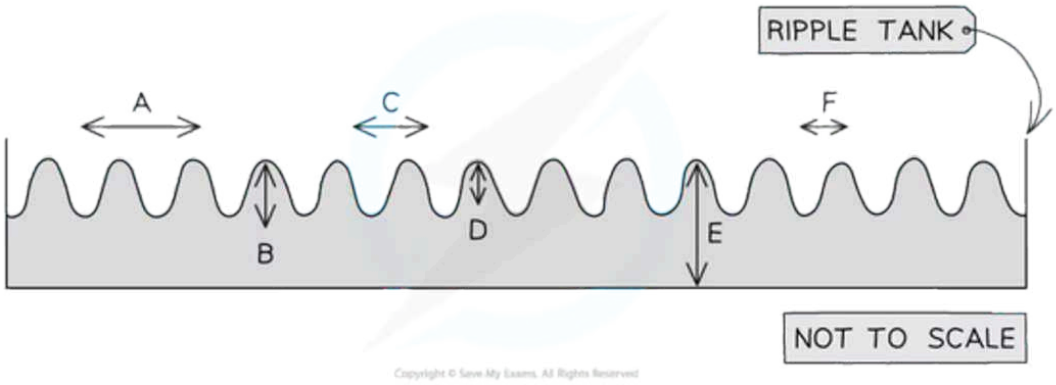
Your notes

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Your notes

Worked example

Small water waves are created in a ripple tank by a wooden bar. The wooden bar vibrates up and down hitting the surface of the water. The diagram below shows a cross-section of the ripple tank and water.



Identify the letter which shows:

a) The amplitude of a water wave.
b) The wavelength of the water wave.

Answer:

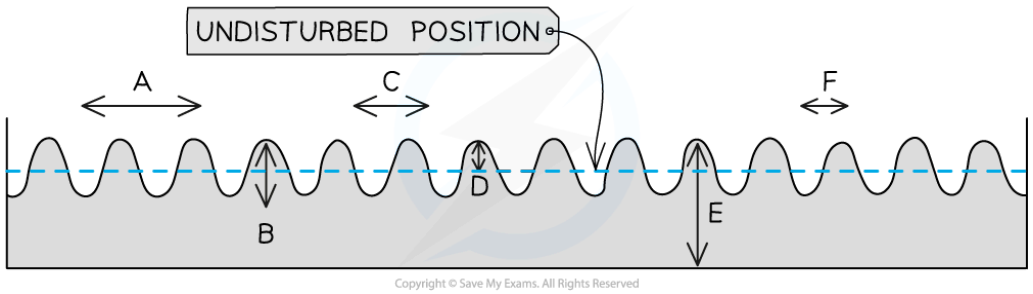
(a)

Step 1: Recall the definition of amplitude

- Amplitude = The distance from the undisturbed position to the peak or trough of a wave

Step 2: Mark the undisturbed position on the wave

- This is the centre of the wave



Step 3: Identify the arrow between the undisturbed position and a peak

- The amplitude is shown by arrow **D**

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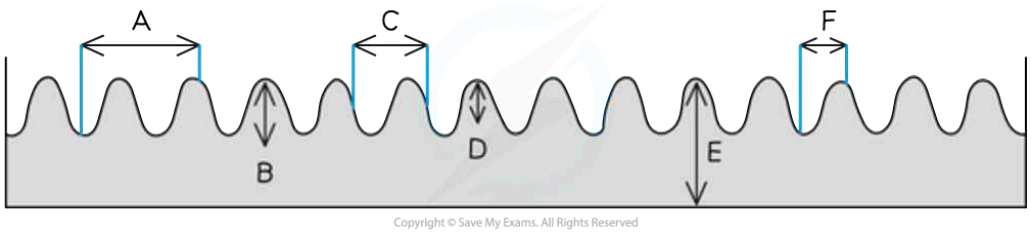
(b)

Step 1: Recall the definition of wavelength

- Wavelength = The distance from one point on the wave to the same point on the next wave

Step 2: Draw lines on each horizontal arrow

- This helps to identify the points on the wave the arrows are referring to



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Step 3: Identify the arrow between two of the same points on the wave

- The wavelength is shown by arrow **C**

Your notes

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The Wave Equation


Your notes

The Wave Equation

- Wave speed is defined as:
 The distance travelled by a wave each second
- Wave speed is given the symbol *v* and is measured in **metres per second (m/s)**
- Wave speed is the speed at which energy is transferred through a medium
- Transverse and longitudinal waves both obey the wave equation:

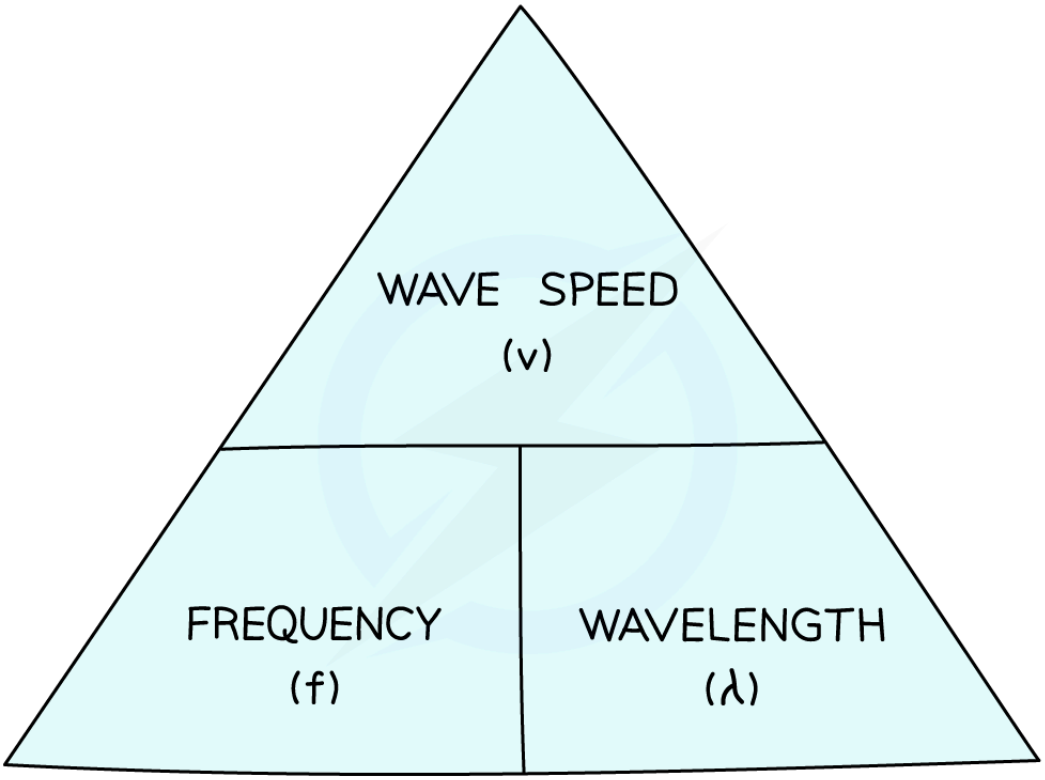
$$v = f \times \lambda$$

- Where:
 - *v* = wave speed in metres per second (m/s)
 - *f* = frequency in hertz (Hz)
 - λ = wavelength in metres (m)
- The wave speed equation may need to be rearranged, which can be done using this formula triangle:

Equation Triangle for the Wave Equation

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Your notes



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Your notes

Worked example

A wave in a pond has a speed of 0.15 m/s and a time period of 2 seconds. Calculate:

a) The frequency of the wave

b) The wavelength of the wave

Answer:

(a)

Step 1: List the known quantities

- Time period, $T = 2$ s

Step 2: Write out the equation relating time period and frequency

$$f = \frac{1}{T}$$

Step 3: Rearrange for frequency, f, and calculate the answer

$$f = \frac{1}{2}$$

Frequency, $f = 0.5$ Hz

(b)

Step 1: List the known quantities

- Wave speed, $v = 0.15$ m/s
- Frequency, $f = 0.5$ Hz

Step 2: Write out the wave speed equation

$$v = f \times \lambda$$

Step 3: Rearrange the equation to calculate the wavelength

$$\lambda = \frac{v}{f}$$

Step 4: Use the frequency you calculated in part (a) and put the values into the equation

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$$\lambda = \frac{0.15}{0.5}$$

Wavelength, $\lambda = 0.30$ m



Your notes

Exam Tip

When stating equations make sure you use the right letters:

For example, use λ for wavelength, not L or W

If you can't remember the correct letters, then just state the word equations

Be careful with units: wavelength is usually measured in metres and speed in m/s, but if the wavelength is given in cm you might have to give the speed in cm/s

Likewise, watch out for frequency given in kHz: 1 kHz = 1000 Hz

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Transverse & Longitudinal Waves

Your notes

Transverse Waves

- Waves are repeated vibrations that transfer **energy**
- Waves can exist as one of two types:
 - **Transverse**
 - **Longitudinal**

Transverse Waves

- Transverse waves are defined as:

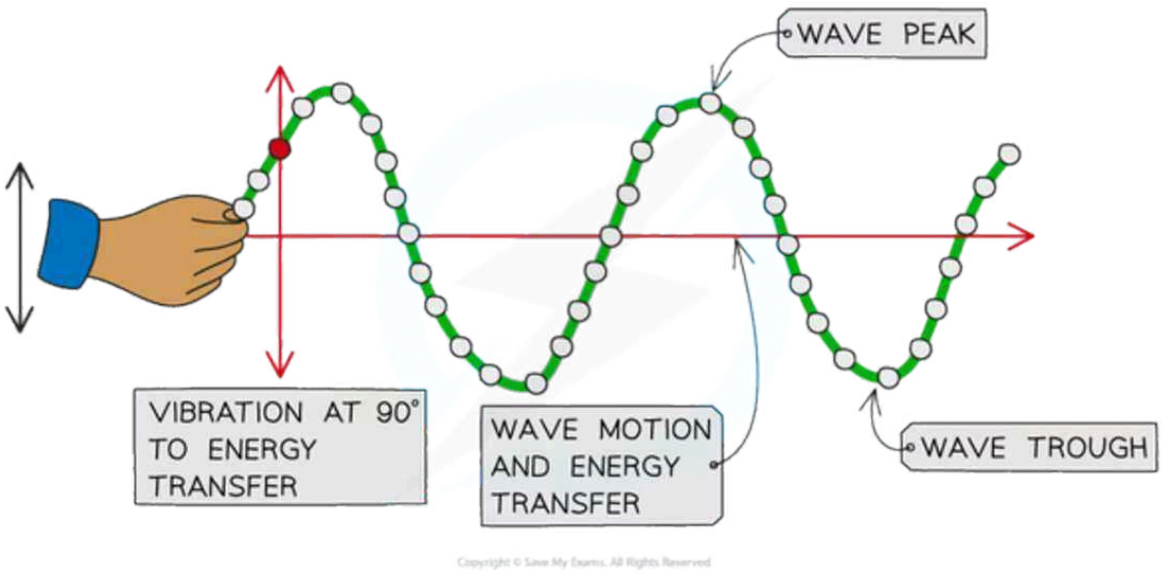
 Waves where the points along its length vibrate at 90 degrees to the direction of energy transfer

- For a transverse wave:
 - The energy transfer is in the **same direction** as the wave motion
 - They transfer energy, but not the particles of the medium
 - They can move in **solids** and on the **surfaces of liquids** but **not** inside liquids or gases
 - Some transverse waves (electromagnetic waves) can move in solids, liquids and gases and in a vacuum
- The point on the wave that is:
 - The highest above the rest position is called the **peak**, or **crest**
 - The lowest below the rest position is called the **trough**

Vibrations of a Transverse Wave

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Your notes



Transverse waves can be seen in a rope when it is moved quickly up and down

- Examples of transverse waves are:
 - Ripples on the surface of water
 - Vibrations on a guitar string
 - S-waves (a type of seismic wave)
 - Electromagnetic waves (such as radio, light, X-rays etc)

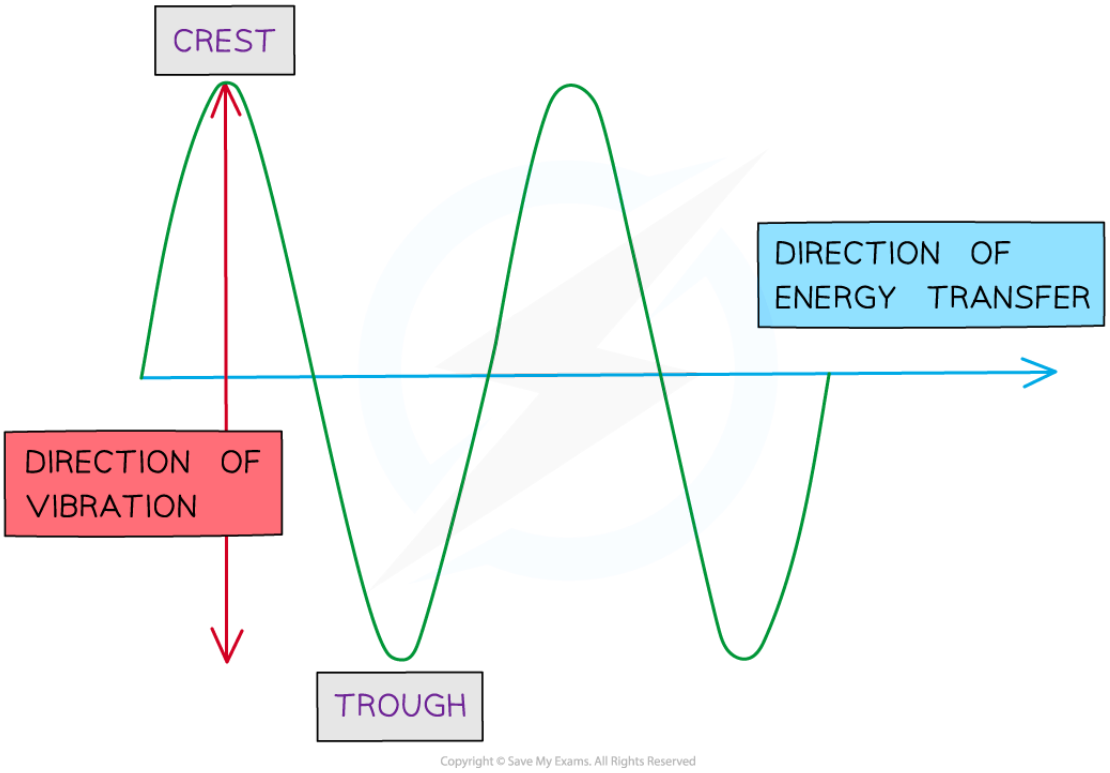
Representing Transverse Waves

- Transverse waves are drawn as a single continuous line, usually with a central line showing the **undisturbed position**
- The curves are drawn so that they are **perpendicular** to the direction of energy transfer
 - These represent the peaks and troughs

Transverse Wave Graph

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Your notes



Transverse waves are represented as a continuous solid line

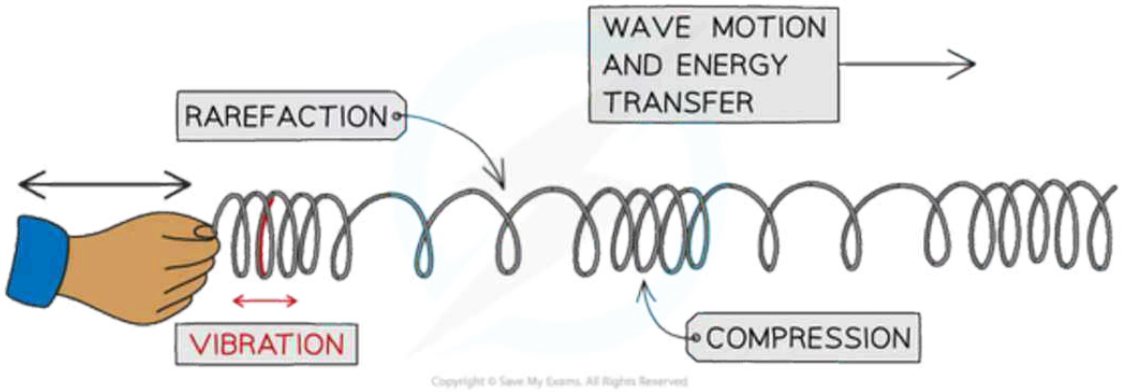
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Longitudinal Waves

Your notes

- Longitudinal waves are defined as:
 Waves where the points along its length vibrate parallel to the direction of energy transfer
- For a longitudinal wave:
 - The energy transfer is in the **same direction** as the wave motion
 - They transfer energy, but not the particles of the medium
 - They can move in solids, liquids and gases
 - They can **not** move in a vacuum (since there are no particles)
- The key features of a longitudinal wave are where the points are:
 - Close together, called **compressions**
 - Spaced apart, called **rarefactions**

Longitudinal Wave on a Spring



Longitudinal waves can be seen in a slinky spring when it is moved quickly backwards and forwards

- Examples of longitudinal waves are:
 - Sound waves
 - P-waves (a type of seismic wave)
 - Pressure waves caused by repeated movements in a liquid or gas

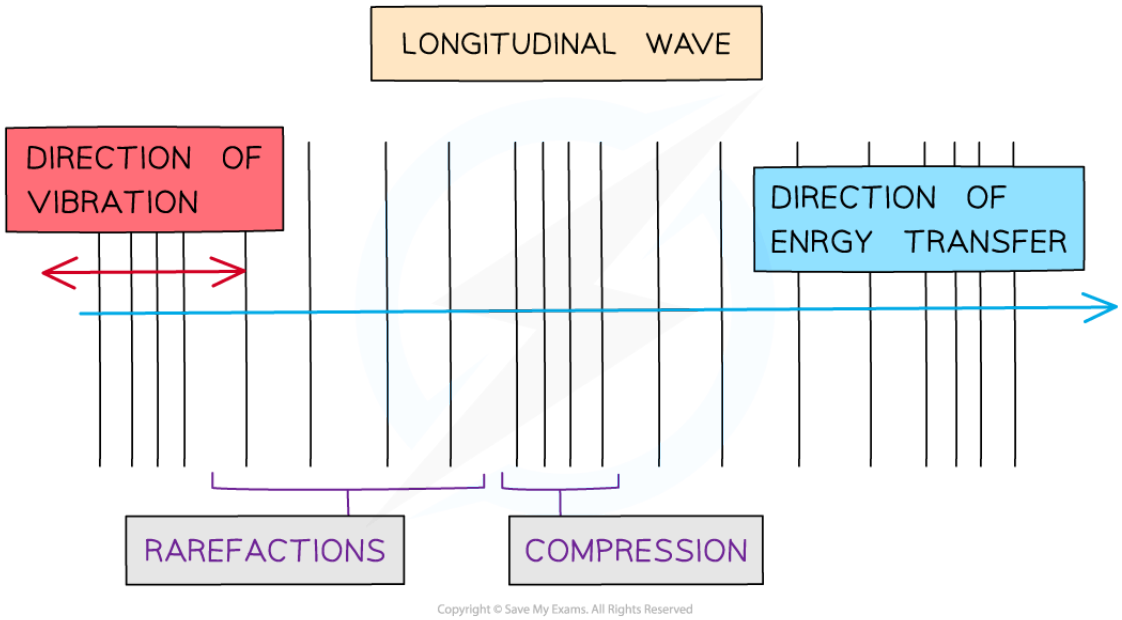
Representing Longitudinal Waves

- Longitudinal waves are usually drawn as several lines to show that the wave is moving **parallel** to the direction of energy transfer
 - Drawing the lines closer together represents the **compressions**
 - Drawing the lines further apart represents the **rarefactions**

Diagram of a Longitudinal Wave

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Your notes



Longitudinal waves are represented as sets of lines with rarefactions and compressions

Comparing Transverse & Longitudinal Waves

- The different properties of transverse and longitudinal waves are shown in the table:

Transverse Waves v Longitudinal Waves Table

Property	Transverse Waves	Longitudinal Waves
Structure	Peaks and troughs	Compressions and rarefactions
Vibration	90° to direction of energy transfer	Parallel to direction of energy transfer
Vacuum	Electromagnetic waves (a transverse wave) can travel through a vacuum	Cannot travel in a vacuum
Material	Can move in solids, liquids and gases	Can move in solids, liquids and gases
Density	Constant density	Changes in density

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Pressure	Constant pressure	Changes in pressure
Speed of wave	Dependent on the material it travels in	Dependent on the material it travels in


Your notes

Exam Tip

The key difference between transverse and longitudinal waves is the direction of the vibrations with respect to the direction of the wave itself. For transverse waves, these are perpendicular to each other, whilst for longitudinal waves, these are parallel.

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Wave Behaviour

Your notes

Reflection, Refraction & Diffraction

- All waves, whether transverse or longitudinal, can be **reflected, refracted** and **diffracted**

Reflection

- Reflection occurs when:

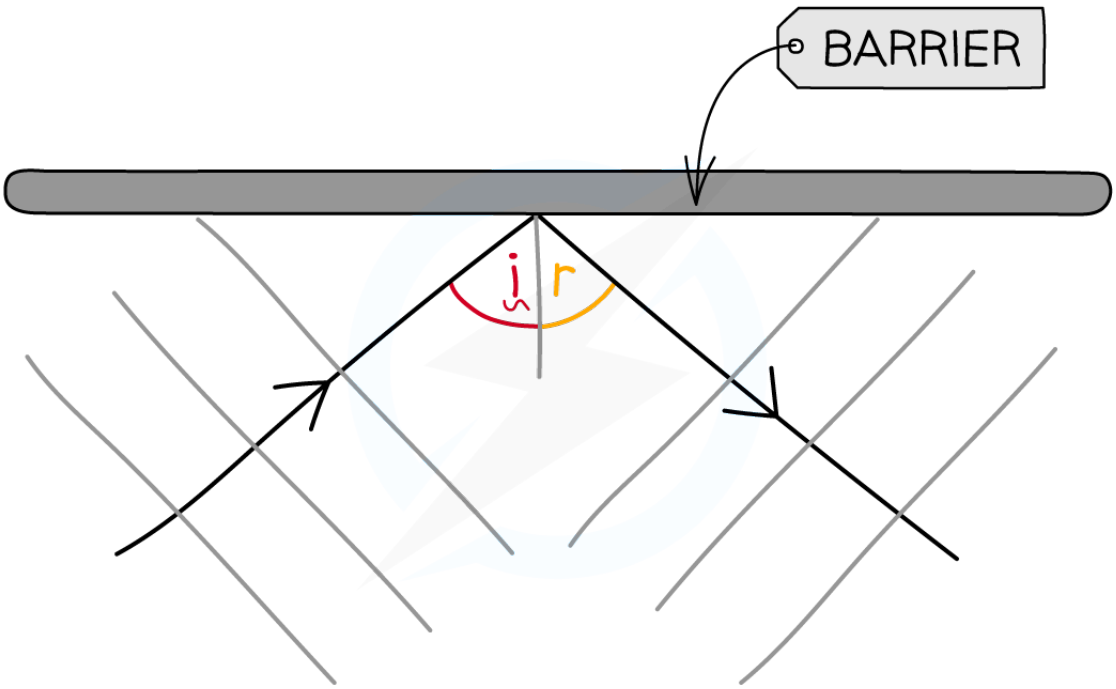
 A wave hits a boundary between two media and does not pass through, but instead stays in the original medium

- The law of reflection states:

 The angle of incidence = The angle of reflection

- When waves hit an object, such as a barrier, they can be reflected:

Reflection



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When waves reflect off a barrier, the angle of reflection, r, is equal to the angle of incidence, i

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Your notes

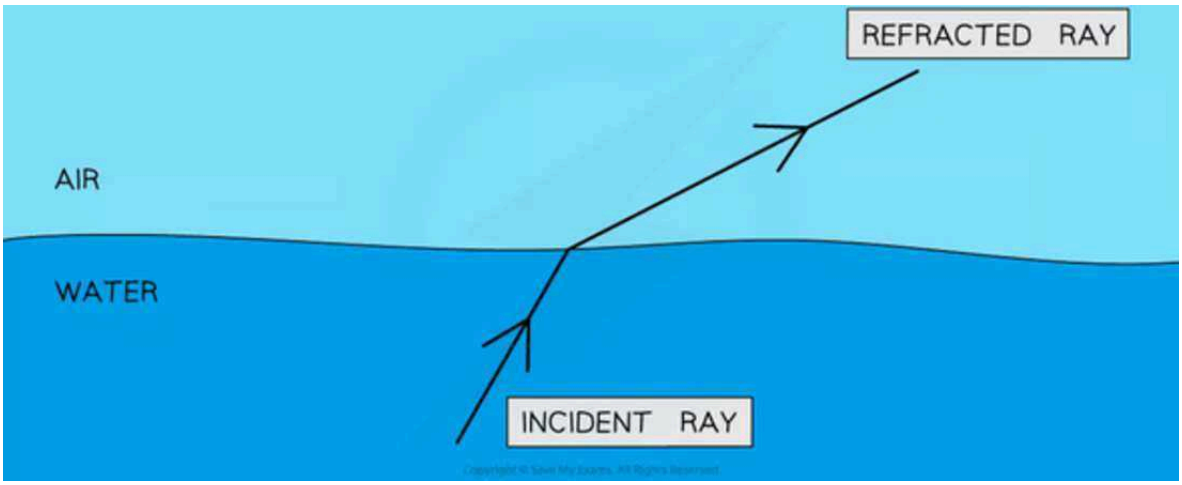
Refraction

- Refraction occurs when:

 A wave passes a boundary between two different transparent media and undergoes a change in direction

- When waves enter a different medium, their speed can change
- This effect is called **refraction**, and it can have two other effects:
 - The wavelength of the waves can increase or decrease
 - The waves can change direction

Refraction



Waves can change direction when moving between materials with different densities

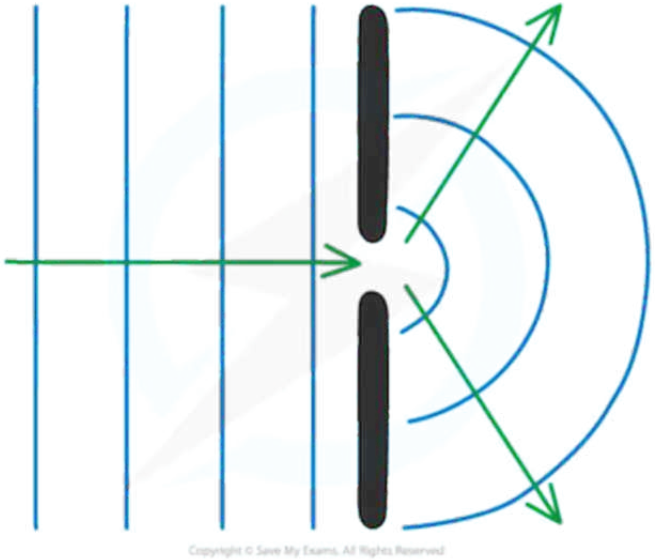
- If the waves **slow down**, the waves will bunch together, causing the wavelength to decrease
 - The waves will also start to turn slightly **towards** the normal
- If the waves **speed up** then they will spread out, causing the wavelength to increase
 - The waves will also turn slightly **away from** the normal

Diffraction

- When waves pass through a narrow gap, **the waves spread out**
- This effect is called **diffraction**

Diffraction

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Diffraction: when a wave passes through a narrow gap, it spreads out

Exam Tip

When drawing waves being reflected take care to:

- Make sure that the angle of incidence is equal to the angle of reflection
- Keep the wavelength of the waves the same

Similarly, when waves are diffracted **the wavelength remains constant.**

Refraction is the only wave effect in which the wavelength changes.

Remember:

Refraction is the name given to the change in the speed of a wave when it passes from one medium to another. The change in direction is a consequence of this.

Your notes

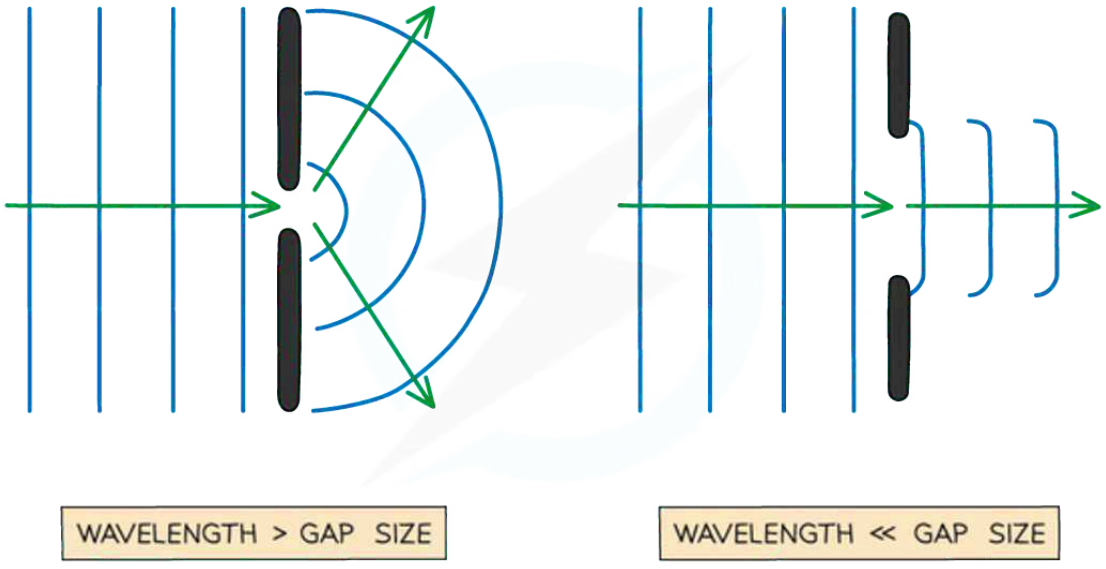
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Factors Affecting Diffraction

Your notes

- Diffraction, as shown above, only generally happens when the gap is smaller than the wavelength of the wave
- As the gap gets bigger, the effect gradually gets less pronounced until, in the case that the gap is very much larger than the wavelength, the waves no longer spread out at all

Diffraction and Gap Size



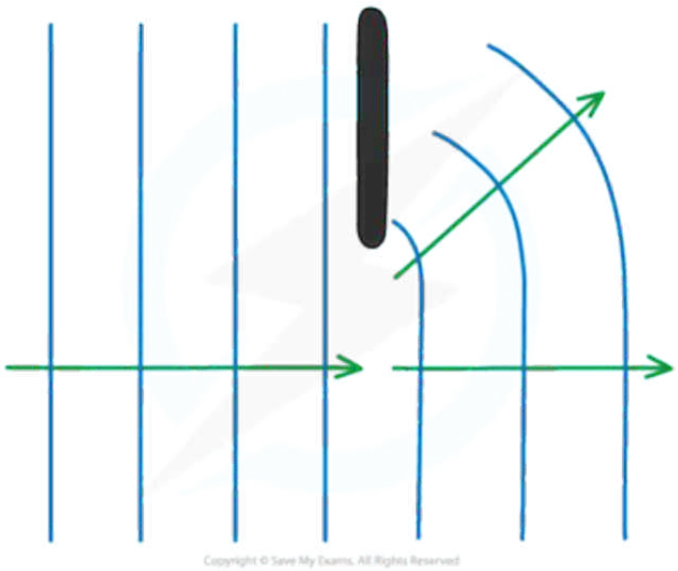
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The size of the gap (compared to the wavelength) affects how much the waves spread out

- Diffraction can also occur when waves pass an edge

Diffraction around an Edge

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When a wave goes past the edge of a barrier, the waves can curve around the edge

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Ripple Tank

Your notes

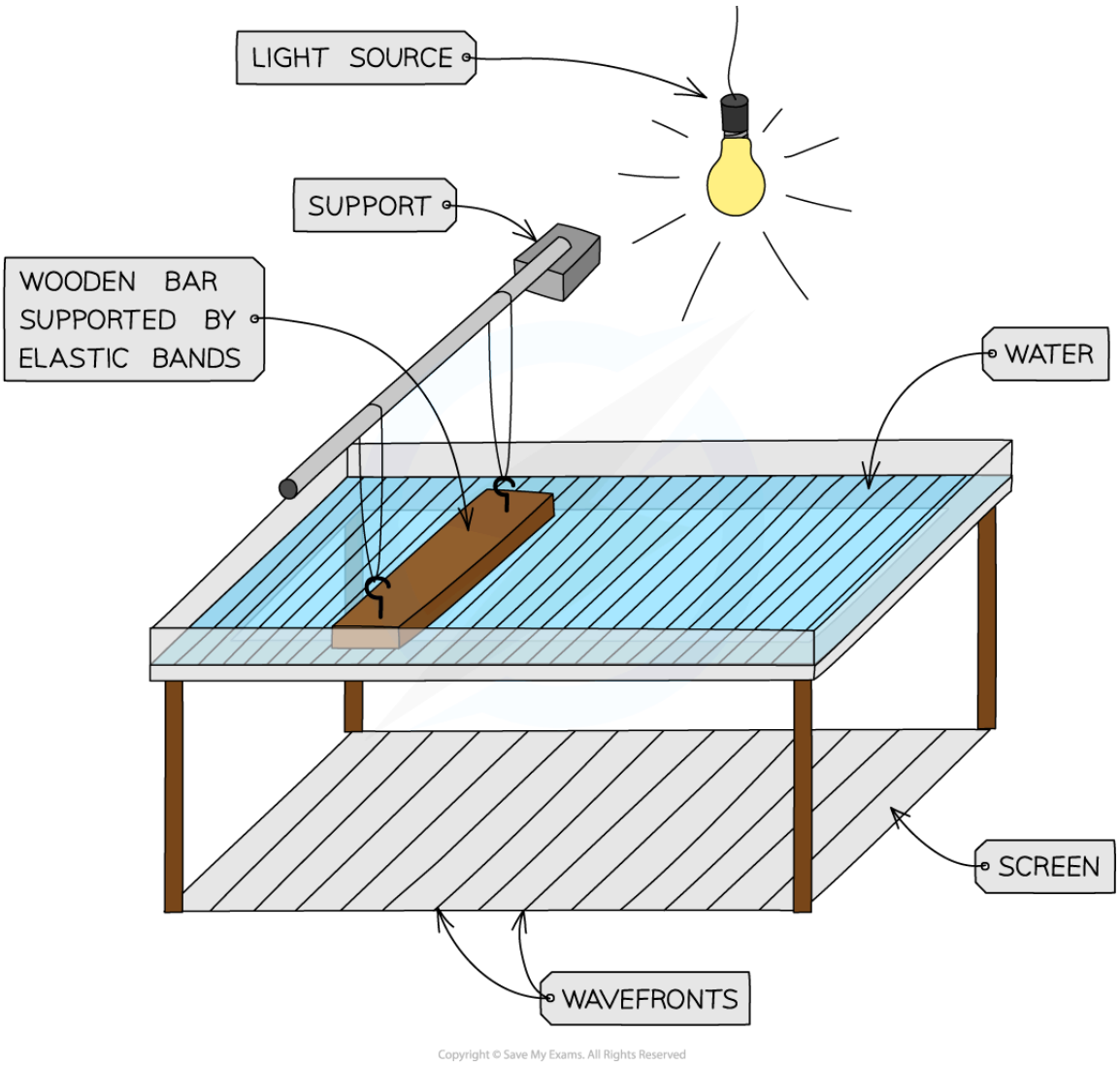
Investigating Waves with a Ripple Tank

- Ripple tanks are commonly used in experiments to demonstrate the following properties of water waves:
 - **Reflection** at a plane surface
 - **Refraction** due to a change in speed caused by a change in depth
 - **Diffraction** due to a **gap**
 - **Diffraction** due to an **edge**

Ripple Tank Apparatus

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Your notes



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Reflection, refraction and diffraction can be demonstrated using a ripple tank

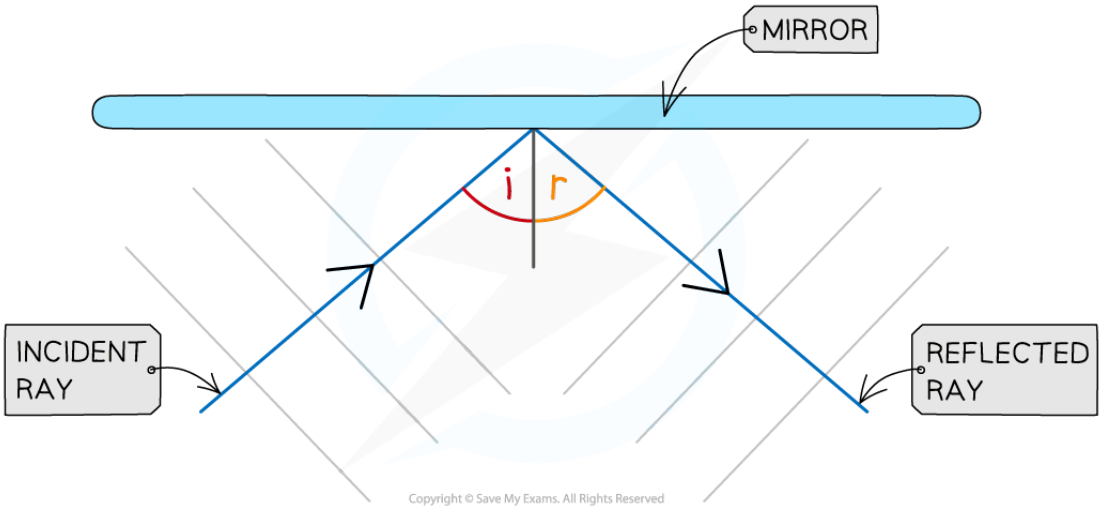
Investigating Reflection

- Reflection can be shown by the waves hitting a plane (straight) surface, such as a wall or mirror

Reflection in a Ripple Tank

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Your notes



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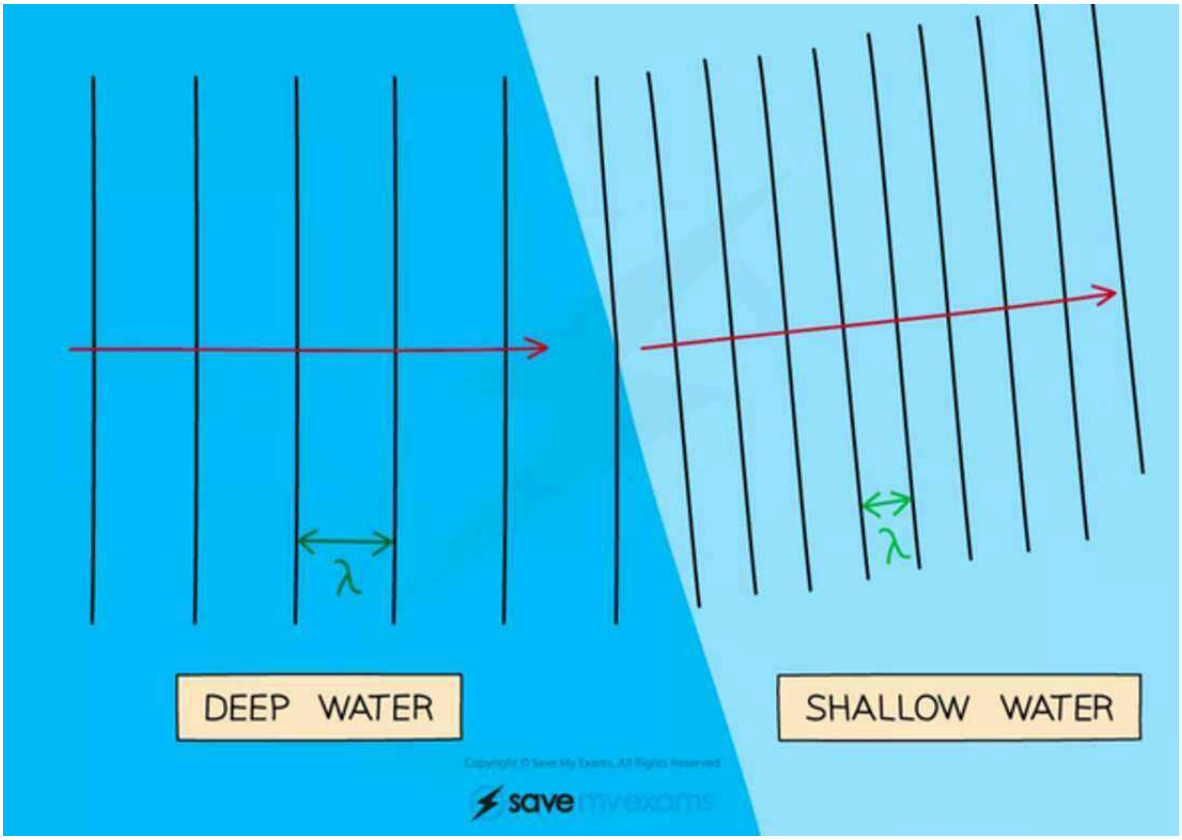
Investigating Refraction

- Refraction can be shown by placing a glass block in the tank
 - The glass block should sit below the surface of the water and cover only some of the tank floor
- The depth of water becomes shallower here the glass block is placed
 - Since speed depends on depth, the ripples slow down when travelling over the block
- This is a good model of refraction showing how waves slow down when passing from deep water into shallow water

Refraction in a Ripple Tank

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Your notes



When water waves travel from deep areas to shallow areas they slow down

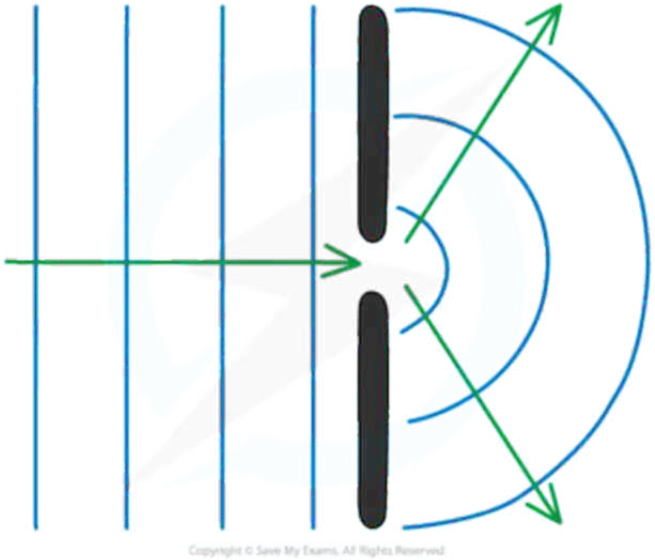
Investigating Diffraction

- Diffraction can be shown in a ripple tank by placing small barriers and obstacles in the tank
- As the water waves encounter two obstacles with a gap between them, the waves can be seen to spread out as follows:

Diffraction through a Gap in a Ripple Tank

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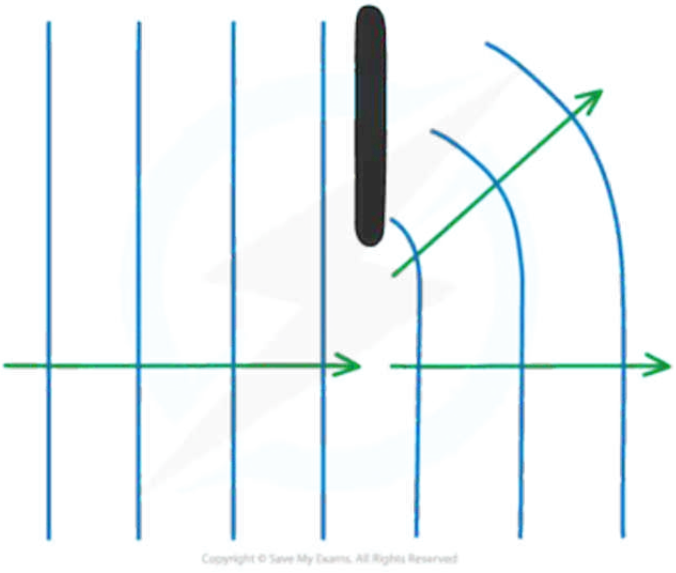
Your notes



Diffraction of water waves through a gap

- As the water waves encounter the edge of an obstacle, the waves can be seen to spread out as follows:

Diffraction round an Edge in a Ripple Tank



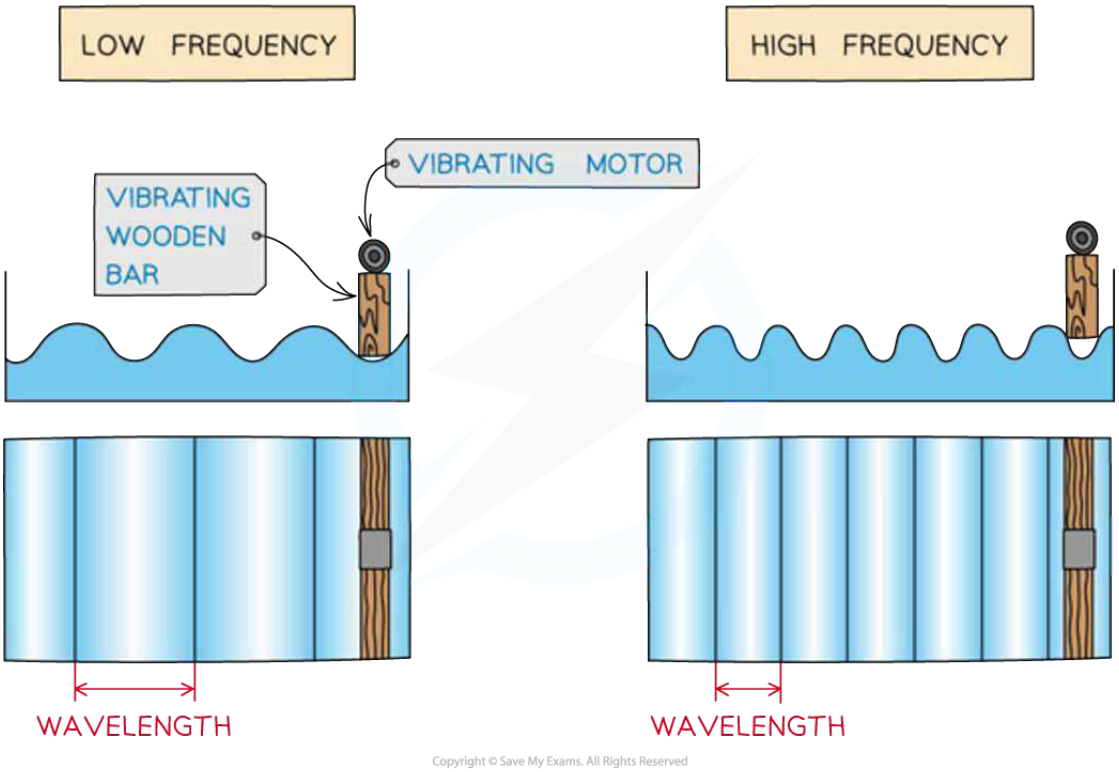
Diffraction of water waves after passing an edge

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- The amount of diffraction depends on the **size of the gap** compared to the **wavelength** of the water wave
- The diagram below shows how the wavelengths differ with frequency in a ripple tank
 - The **higher** the frequency of the motor, the **shorter** the wavelength
 - The **lower** the frequency of the motor, the **longer** the wavelength

Your notes

Generating Waves in a Ripple Tank



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Ripple tank patterns for low and high frequency vibration

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Cambridge O Level Physics

Your notes

3.2 Light

Contents

- Reflection of Light
- Investigating Reflection
- Refraction of Light
- Snell's Law
- Total Internal Reflection
- Thin Lenses
- Real & Virtual Images
- Linear Magnification
- Uses of Lenses
- Dispersion of Light

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Reflection of Light

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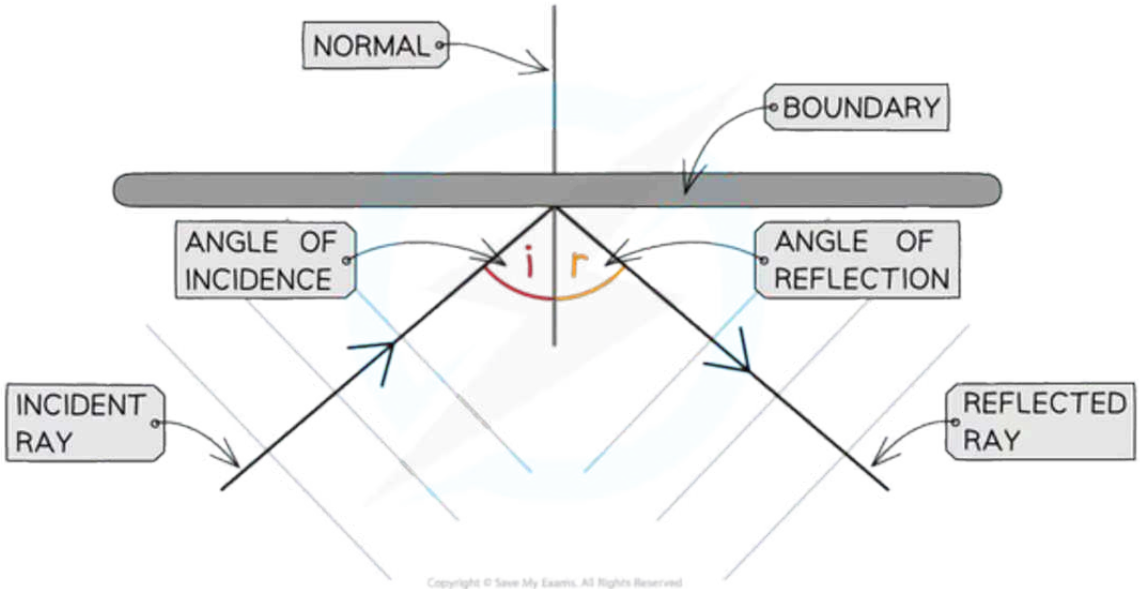
Ray Diagrams

- Angles are measured between the wave direction (ray) and a line at 90 degrees to the boundary
 - The angle of the wave approaching the boundary is called the **angle of incidence (i)**
 - The angle of the wave leaving the boundary is called the **angle of reflection (r)**
- The line at right angles (90°) to the boundary is known as the **normal**

- When drawing a ray diagram an arrow is used to show the direction the wave is travelling
 - An **incident** ray has an arrow pointing **towards** the boundary
 - A **reflected** ray has an arrow pointing **away** from the boundary

- The **angles** of **incidence** and **reflection** are usually labelled **i** and **r** respectively

Reflection



A ray diagram for light reflecting at a boundary, showing the normal, angle of incidence and angle of reflection

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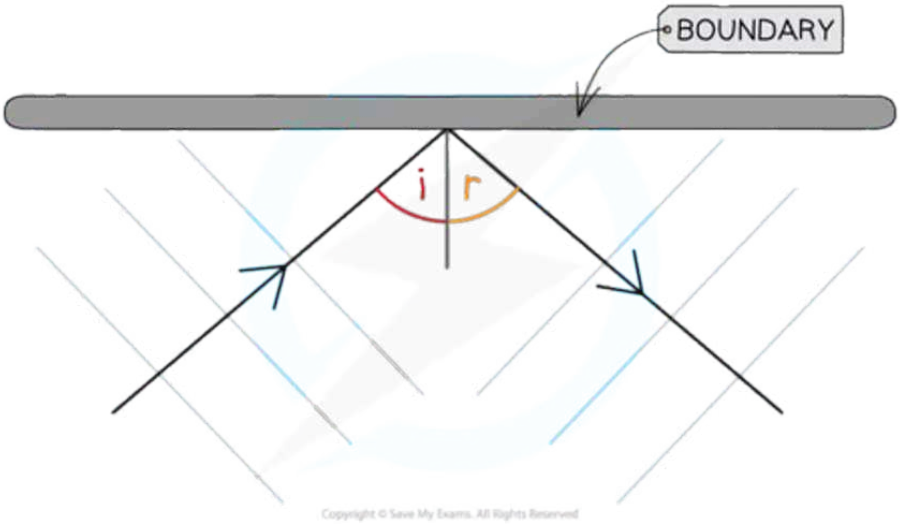
The Law of Reflection

Your notes

- The **law of reflection** states that these angles are the same:

Angle of incidence (i) = Angle of reflection (r)

Law of Reflection



Reflection of a wave at a boundary, i = r

Exam Tip

When drawing light waves being reflected **take care to get the angles equal.**

If they are slightly out it won't be a problem, but if there is an obvious difference between the angle of incidence and the angle of reflection then you will lose a mark. Use a protractor to be sure of the angles.

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Investigating Reflection

Your notes

Investigating Reflection

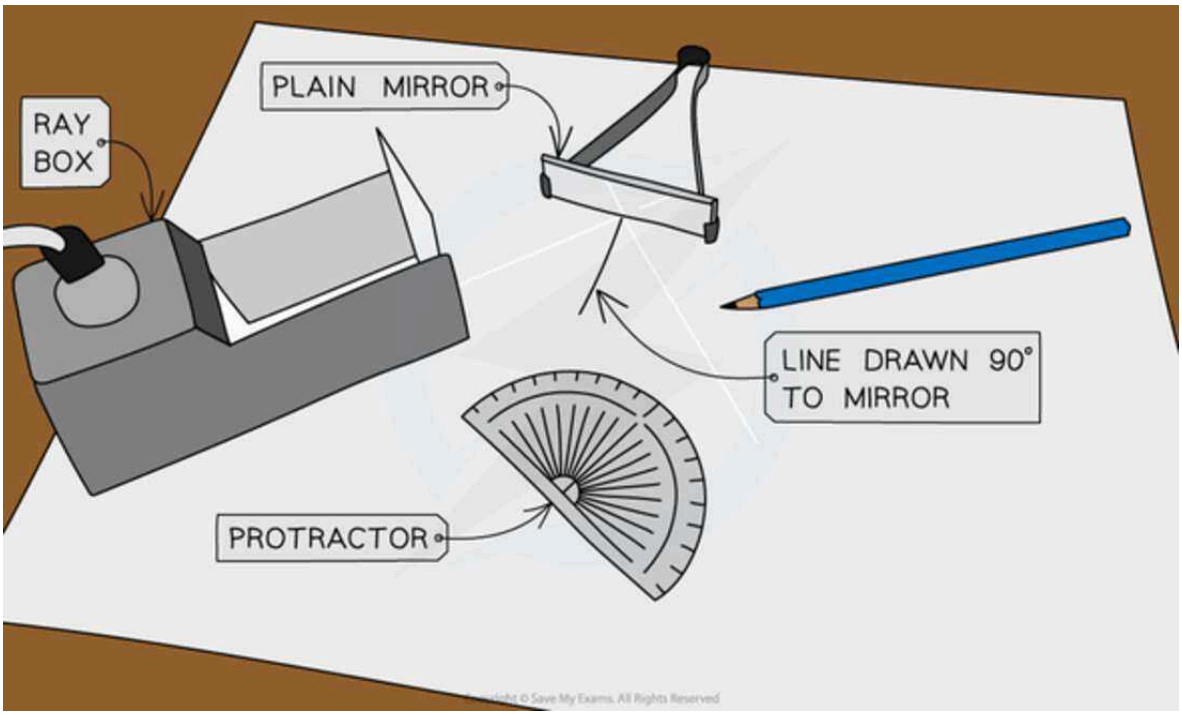
Aims of the Experiment

- To investigate reflection by a plane mirror

Variables

- Independent variable = angle of incidence, *i*
- Dependent variable = angle of reflection, *r*
- Control variables:
 - Distance of ray box from mirror
 - Width of the light beam
 - Same frequency / wavelength of the light

Method



Apparatus to investigate reflection

1. Set up the apparatus as shown in the diagram

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2. In the middle of the paper use a ruler to mark a straight line of about 10 cm long
3. Use a protractor to draw a 90° line that bisects (cuts in half) the 10 cm line
4. Place the mirror on the first line as shown in the diagram above
5. Switch on the ray box and aim a beam of light at the point where the two drawn lines cross at an angle
6. Use the pencil to mark two positions of the light beam:
 - A point just after leaving the ray box
 - The point on the reflected beam about 10 cm away from the mirror
7. Remove the ray box and mirror
8. Use a ruler to join the two marked positions to the point where the originally drawn lines crossed
9. Use the protractor to measure the two angles from the 90° line. The angle for the ray towards the mirror is the angle of incidence, and the other is the angle of reflection
10. Repeat the experiment three times with the beam of light aimed at different angles

- An example of the data collection table is shown below:

Example Results Table

Angle of Incidence, *i* / °	Angle of Reflection, *i* / °
10	
30	
45	
80	

Analysis of Results

- The law of reflection states:

$$i = r$$

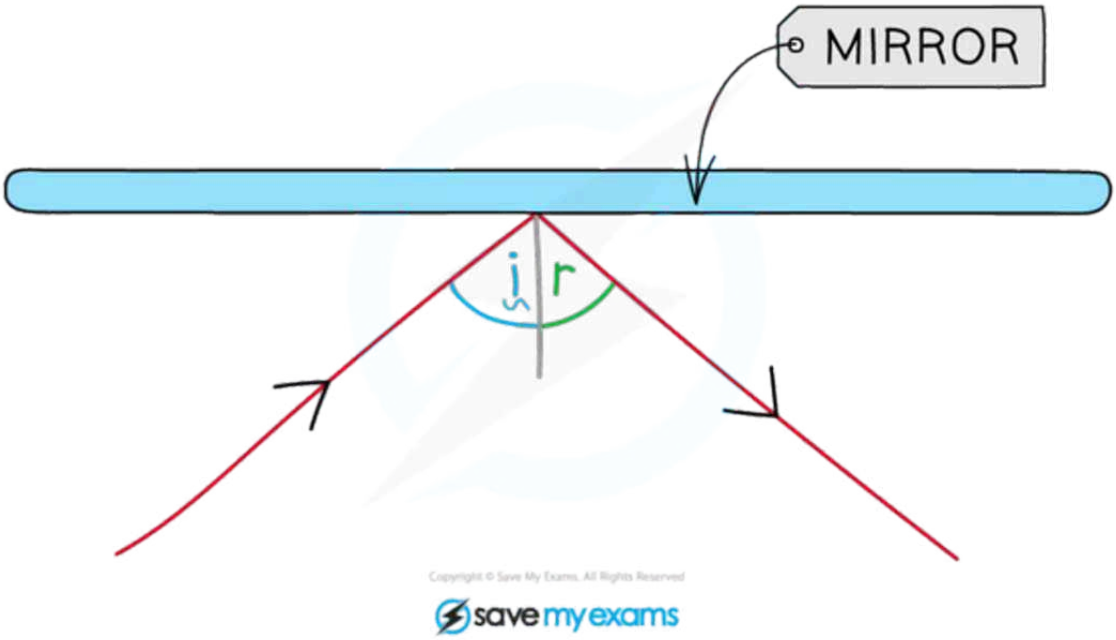
- Where:
 - *i* = angle of incidence in degrees (°)
 - *r* = angle of reflection in degrees (°)

Your notes

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- If the experiment was carried out correctly, the angles should be the same, as shown below:

Correct Results of the Experiment



Law of reflection demonstrated correctly

Evaluating the Experiment

Systematic Errors:

- An error could occur if the 90° lines are drawn incorrectly
 - Use a set square to draw perpendicular lines
- If the mirror is distorted, this could affect the reflection angle, so make sure there are little to no blemishes on it

Random Errors:

- The points for the incoming and reflected beam may be inaccurately marked
 - Use a sharpened pencil and mark in the middle of the beam
- The protractor resolution may make it difficult to read the angles accurately
 - Use a protractor with a higher resolution

Safety Considerations

Your notes

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- The ray box light could cause burns if touched
 - Run burns under cold running water for at least five minute
- Looking directly into the light may damage the eyes
 - Avoid looking directly at the light
 - Stand behind the ray box during the experiment
- Keep all liquids away from the electrical equipment and paper
- Take care using the mirror
 - Damages on the mirror can affect the outcome of the reflection experiment



Your notes

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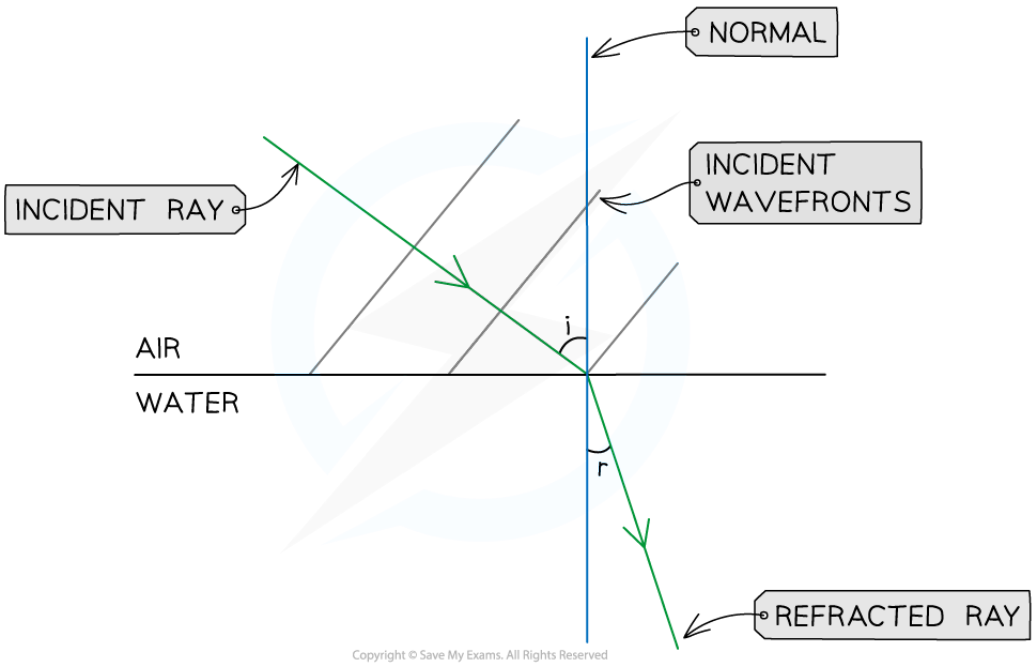
Refraction of Light

Your notes

Ray Diagrams for Refraction

- When drawing refraction ray diagrams, angles are measured between the wave direction (ray) and a line at 90 degrees to the boundary
 - The angle of the wave approaching the boundary is called the **angle of incidence (i)**
 - The angle of the wave leaving the boundary is called the **angle of refraction (r)**
- The line at right angles (90°) to the boundary is known as the **normal**
- When drawing a ray diagram an arrow is used to show the direction the wave is travelling
 - An **incident** ray has an arrow pointing **towards** the boundary
 - A **refracted** ray has an arrow pointing **away** from the boundary
- The **angles** of **incidence** and **refraction** are usually labelled **i** and **r** respectively
- The change in direction depends on which media the light rays pass between:
 - From less dense to more dense (e.g air to glass), light bends **towards** the normal
 - From more dense to less dense (e.g. glass to air), light bends **away** from the normal
 - When passing along the normal (perpendicular) the light **does not bend** at all

Refraction from Less Dense Medium to More Dense Medium



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A ray diagram for light refracting at a boundary, showing the normal, angle of incidence and angle of refraction. The ray bends towards the normal as it is passing into a more dense medium.

Your notes

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Investigating Refraction


Your notes

Aim of the Experiment

- To investigate the refraction of light using rectangular blocks, semi-circular blocks and triangular prisms

Variables

- Independent variable = shape of the block
- Dependent variable = direction of refraction
- Control variables:
 - Width of the light beam
 - Same frequency / wavelength of the light

Equipment List

Energy Store	Description
Ray box	to provide a narrow beam of light to refract in the perspex blocks
Protractor	to measure the angles of refraction
Sheet of paper	to mark the rays of light and the outlines of the blocks
Pencil	Magnetic interacting with each other have energy in their magnetic store
Ruler	to draw the rays of light and the outlines of the blocks
Perspex blocks (rectangular, semi-circular & prism)	to refract the rays of light

- Resolution of measuring equipment:
 - Protractor = 1°
 - Ruler = 1 mm

Ray Box and Blocks

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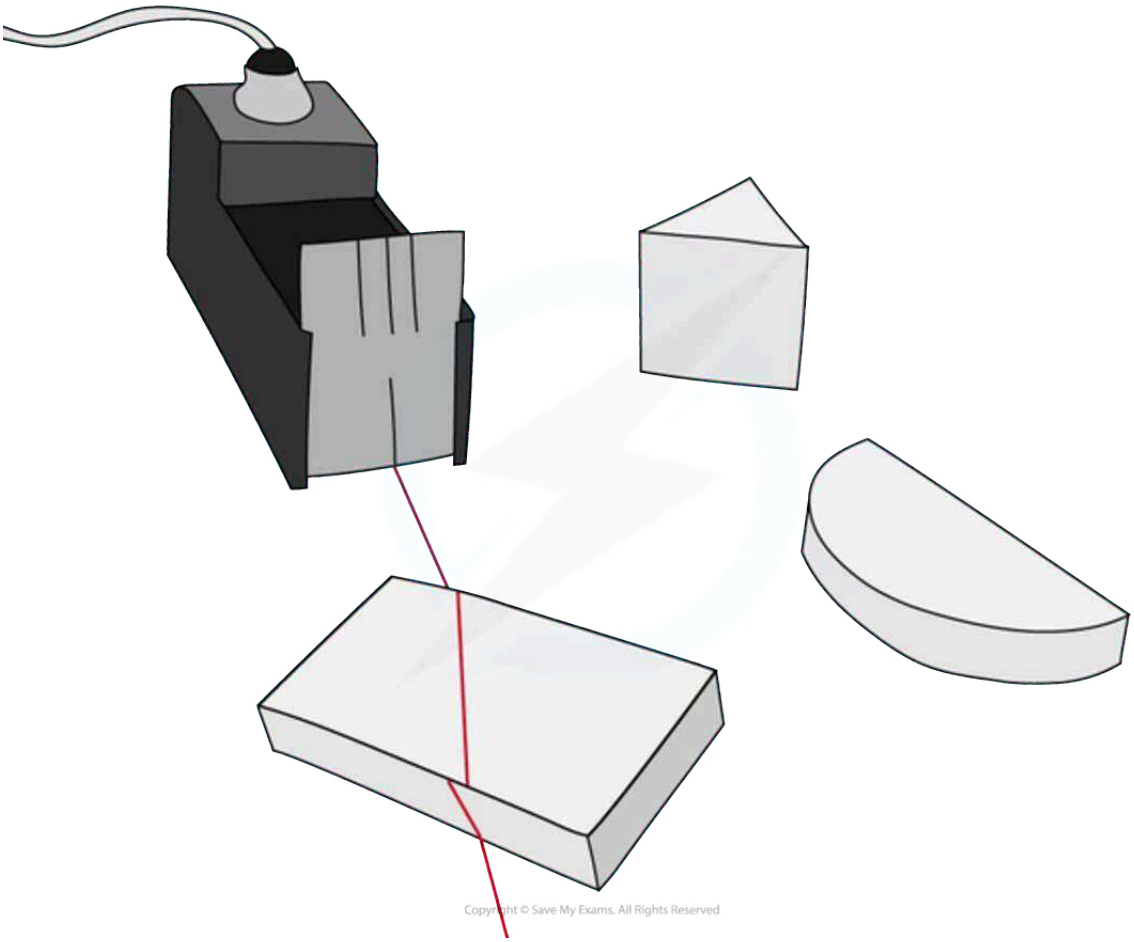


Diagram showing a ray box alongside three different shaped glass blocks

Method

Diagram Showing Tracing Method

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